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Childhood Innovation: Development, Facilitators, and Individual Variation

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A thesis submitted for the degree of Doctor of Philosophy in the

Department of Psychology at Durham University

December 2015

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Declaration

I confirm that no part of the material presented in this thesis has previously been submitted for a degree in this or any other institution. If material has been generated through joint work, this has been indicated where appropriate. All other sources have been referenced, and quotations suitably indicated.

Statement of Copyright

The copyright of this thesis rests with the author. No quotation from it should be published without the author's prior written consent and information derived from it should be acknowledged.

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This thesis is dedicated to my mum and dad.

Thesis Abstract

This thesis investigated the development, consistency and facilitators of children's innovation in the physical, tool-use domain. Despite gaining increasing interest in developmental psychology, understanding of the ontogeny of innovation remains in its infancy. Following the formulation of an operational definition of innovation and associated criteria in Chapter 2, the innovatory ability of 4- to 9-year-old children was examined using the Multiple-Methods Box (MMB): a novel puzzle box from which a reward can be extracted using different tools, access points and exits. Findings reported in Chapter 3 demonstrated that few children innovated in the aftermath of social demonstrations of tool use (akin to innovation by modification); rather, they largely relied on the observed task solution. However, instances and rates of children's innovation were seen to increase in response to inefficacious social information (Chapter 3) and when provided with additional time and explicit instructions/prompts to explore the MMB (Chapter 6). Individual differences in children's innovative or imitative behaviour appeared largely independent of their performance on a battery of tasks assessing constructs related to innovation, as explored in Chapter 4. However, this study revealed some behavioural consistency in puzzle-box contexts, suggestive of consistent individual differences in children's propensity, or preference, to engage in asocial/individual learning. Finally, in the intervention study of Chapter 5, individual achievement goals appeared of greater salience than cues to conventionality of innovative behaviour, which did not differentially enhance 8- to 9-year-olds' innovation when presented with the MMB task in the absence of social demonstrations. Together, the thesis findings highlight the value of the dual study of imitation and innovation, in discovering adaptive trade-

offs between the two, and the need to consider innovation in its various forms, owing to likely disparities in developmental trajectories, cognitive requirements, and primary difficulties. The educational applications and cultural implications are discussed.

Note on Publications

At the time this thesis was submitted for examination, one chapter had been published and one chapter was accepted for publication.

Chapter 2:

Carr, K., Kendal, R.L., & Flynn, E.G. (accepted). Eureka!: What is innovation, how does it develop and who does it? *Child Development*.

Chapter 3:

Carr, K., Kendal, R.L., & Flynn, E.G. (2015). Imitate or innovate? Children's innovation is influenced by efficacy of observed behaviour. *Cognition*, 142, 322-332.

As lead author, I was responsible for reviewing and synthesising the literature, collecting and analysing data, and writing up results/theoretical conclusions. My supervisors and co-authors help to refine experimental designs, provide input in analysis and interpretation, and give feedback in the write up.

These chapters are presented as they were accepted. However, any American English spelling has been altered to British English and the numbering system has been altered for consistency throughout the thesis. Where appropriate, cross-references between chapters have also been made.

Note on Ethics

Prior to undertaking each empirical study, a written ethics application was made to Durham University's Psychology Department Ethics Committee. Within this application it was confirmed that the proposed research adhered to the British Psychological Society (BPS) Code of Ethics and Conduct, and detail was given of the purpose of the project, methods and measurements, participants, along with intended consent and participant information and a statement of ethical considerations. Empirical studies commenced when ethical approval was granted by the department. A sample ethics consent letter is provided in Appendix Item 1a, along with emails from the departmental Ethics Committee granting approval for the studies (Appendix Item 1b).

For those studies involving children, written informed consent was gained from school Head teachers and parents/guardians, and verbal consent was gained from the children themselves. All participating adults signed an information and consent form prior to taking part and were fully debriefed following participation.

Chapter 1

General Introduction

When we consider the remarkable advances that have been made by humans, whether putting people on the moon, developing antibiotics and vaccines to treat deadly diseases, creating literary and artistic masterpieces, or colonising virtually every corner of the earth, we apprehend that *innovation* is foundational to our greatest achievements. In a changing world, innovation – denoting, in its simplest sense, a new idea, product or behaviour – allows us to overcome novel problems and is thus critical to our survival. Though other animal species innovate (Reader & Laland, 2003), the complexity, diversity and breadth of human innovation is unparalleled. Understanding the process and development of innovation, such that its applications may be fully harnessed, is imperative in the light of ever more complex environmental, technological and economic challenges. This pursuit of understanding will allow us to gain, in turn, a more thorough and complete conception of cumulative cultural evolution: an, arguably, uniquely human process and one which likely underpins our species’ exceptional success (Dean, Vale, Laland, Flynn, & Kendal, 2013).

The main lines of investigation within this thesis concern the development and individual consistency of children’s behavioural innovation, along with factors that potentially facilitate (or constrain) it. A necessary consequence of studying innovation, though undoubtedly a fortuitous one in terms of the potential for complementary insight and understanding, is that social learning is heavily implicated in this work. Social learning, involving the acquisition of knowledge from others, can be regarded as the antithesis of innovation: the opposite side of the

cumulative culture coin. Whilst the approach in this thesis is firmly developmental, it draws upon comparative and non-human animal research; primarily, owing to the relative lack of childhood innovation research, though this area has recently been met with increasing attention, and the comparative wealth of non-human animal innovation research, from which there are a number of lessons to be learned. The sections in this introductory chapter overview the motivation for this thesis, the importance and implications of studying innovation, and the terminology and experimental methods employed. It concludes with an outline of the ensuing thesis chapters.

1.1 The Importance of Innovation

Owing to its array of cognitive, cultural and real-world ramifications, innovation is of wide societal interest and importance. From an applications perspective, understanding what facilitates or hinders the innovation process will allow the formulation of interventions to promote it. Though these interventions may be applied in a variety of industries, such as business and healthcare, they may be particularly fruitful in early educational settings wherein cognitive abilities that are associated with, and contribute to, innovation undergo critical developments (and thus may be targeted and advanced). Innovatory capacity supported in childhood could continue into adulthood. Innovation is of relevance not only on an individual level, but also in allowing solutions to novel problems or novel solutions to existing problems (Kummer & Goodall, 1985) to be produced on a wider population and cultural level. Together with social learning (“learning that is influenced by observation of, or interaction with, another animal (typically a conspecific) or its

products”; Heyes, 1994, p.208), innovation plays a vital role in the evolution of culture (Mesoudi et al., 2013; Richerson & Boyd, 2005; Tomasello, 1999). It is this contribution of social learning (in the form of high-fidelity transmission mechanisms) that helps distinguish animal innovations, which largely remain in their original form, from infinitely more complex human innovations.

Innovation is recognised as a major driver of human’s technical and cultural sophistication, enabled by the operation of the ‘ratchet effect’ (Tennie, Call, & Tomasello, 2009; Tomasello, Kruger, & Ratner, 1993). The ratchet effect describes the process by which cultural traits are maintained in populations, and across generations, until a modification or improvement (‘innovation’) is made, with the then modified or improved trait being learned and acquired by individuals in the population. In this way, the cultural trait ‘ratchets up’ in complexity or efficiency such that no single individual could have invented it alone (Boyd & Richerson, 1996; Tomasello et al., 1993; Tomasello, 1999). This process therefore “relies both on inventiveness, for the cultural novelties, and on faithful transmission across generations to keep the novelties in place until other novelties come along” (Tennie et al., 2009, p.2405), thereby preventing trait loss. Cumulative culture is defined by humans’ ratcheting – repeated modification of cultural traits - ability (Dean et al., 2013). It is now widely believed that cumulative cultural evolution is unique to humans (e.g., Dean et al., 2013; Tomasello, 2016) and defining of human culture (Richerson & Boyd, 2005). Innovation thus operates in tandem with, and indeed is reliant upon, high-fidelity transmission mechanisms to effect cumulative cultural change (Lewis & Laland, 2012; Tomasello, 1999). Moreover, the extent to which an innovation becomes established as a population-level tradition, with the opportunity to influence cultural evolution, is moderated by social learning processes, along with

adaptive transmission biases (Boyd & Richerson, 1985) or social learning strategies (Laland, 2004) that help direct what, when and from whom individuals learn.

Humans are separated from other animal species in their capacity for cumulative culture, but also in the fidelity of their social learning (e.g., Horner & Whiten, 2005). As an ‘ultra-social’ species (Herrmann, Call, Hernandez-Lloreda, Hare, & Tomasello, 2007), we desire and seek identification, affiliation and acceptance with our social group. The importance and adaptiveness of social learning, and specifically imitation (wherein the form of an action is copied; Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009), is reflected in the early age at which children come to show themselves as ‘cultural magnets’ (Flynn, 2008) by faithfully reproducing and transmitting observed behaviour (Hopper, Flynn, Wood, & Whiten, 2010). Though not without its potential costs (e.g., unreliable or outdated information acquisition; Boyd & Richerson, 1985; Laland, 2004), social learning provides a powerful shortcut to knowledge and behaviour, whether this is instrumental, in terms of learning how to achieve an explicit goal, or conventional, such as acquiring the cultural norms and rituals of one’s social group (Legare & Nielsen, 2015). The latter motivation is posited responsible for observations of so-called ‘over-imitation’ (Lyons, Young, & Keil, 2007), wherein children (McGuigan, Whiten, Flynn, & Horner, 2007), and indeed adults (Flynn & Smith, 2012; McGuigan, Makinson, & Whiten, 2011), imitate actions that are causally unnecessary to the attainment of a goal (Keupp, Behne, & Rakoczy, 2013). Yet, as early as children display a competence for imitation (Meltzoff, 1985), they display a similarly early competence for selectivity and flexibility in their imitation (e.g., Carpenter, Akhtar, & Tomasello, 1998; Nielsen, 2006; see Over & Carpenter, 2012, 2013); altering the extent, and fidelity, with which they reproduce behaviour in line

with a wide variety of contextual and social cues. The recognition that children are not blind and indiscriminate copiers of observed behaviour, particularly when that behaviour is inefficacious (Schulz, Hoopell, & Jenkins, 2008; Williamson, Meltzoff, & Markman, 2008), and that social learning is most adaptive when selectively utilised (Laland, 2004; see also Kendal, Coolen, & Laland, 2009), contributed to the theoretical rationale for the first empirical study presented in Chapter 3.

Given that there is ample evidence of social learning in childhood, of the high fidelity yet flexible kind necessary to sustain cultural behaviours and traditions (i.e., imitation), is there evidence of innovation? As Legare and Nielsen (2015, p.693) note, “Imitation did not, in isolation, take us from being a cultural animal, like our closest living primate relatives, to a cumulatively cultural one” and thus we might expect to see innovation’s similarly early emergence. Discovering whether and when children opt to innovate, as opposed to imitate, as a function of both development and context, is one of the key research aims of this thesis. Specifically, it will help to shed light on the conditions under which imitation is judged a less effective or appropriate learning strategy. Thus, innovation is of interest not only with regard to cultural evolution but individual development. Though developmental psychologists have been interested in exploratory learning for decades, from Piaget’s early emphasis upon individual discovery for a child’s intellectual development to Gopnik’s (2012) ‘child-as-scientist’ portrayal, innovation as a possible outcome of children’s play, problem solving and exploration requires explicit investigation.

Theoretical approaches, comparative research and non-human animal research are generating invaluable insights into the likely evolutionary origins, functions and emergence of innovation. To complement such findings, developmental studies are needed to establish its ontogeny, early manifestations,

associated cognitive factors and underlying mechanisms. Unlike the advanced understanding of the evolutionary basis of innovation, that of the ontogenetic foundations of innovation remains limited - especially when compared with what is now known of the ontogeny of social learning. This thesis is a response to the need for research in the area of children's innovation.

1.2 Childhood Innovation

As alluded to earlier, there are reasons why studying and promoting innovation in childhood is of importance and why this approach is taken in the current work. First, examining innovation in childhood allows us to compare children's abilities with those of non-human animals (when analogous tasks are used), shedding light onto aspects of cognition that are universal amongst species or, alternatively, uniquely human. This is because children are generally regarded as less enculturated or socialised than adults, making them closer points of comparison (though by no means equivalent). Second, by studying children, we are better placed to capture innovation early. Whilst children are proficient cultural learners from a very early age, evident in their faithful transmission of observed behaviour (Hopper et al., 2010), conformity to peers (Haun & Tomasello, 2011), and ritualistic interpretation of observed actions (Nielsen, Kapitány, & Elkins, 2015), it is probable that they are less bound by cultural conventions and norms than adults. With age, humans appear to become more embedded within normative processes (as shown, for example, with over-imitation; McGuigan et al., 2011), more biased towards existing knowledge (Gopnik, Griffiths, & Lucas, 2015), and more susceptible to the effects of functional fixedness (see below; Defeyter & German, 2003). Of course, at

the same time, with increasing age individuals will be better equipped to overcome such biases and/or produce novel alternative behaviour owing to greater cognitive maturity and flexibility. Third, the cognitive and motivational systems that underpin innovation in childhood are likely to be simpler than those that underpin innovation in adulthood, meaning the connections between innovation and its facilitators may be easier to explore.

All children who participated in the research of this thesis were aged between four and nine years, in line with existing childhood innovation research (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011). This was deemed a sufficiently large age range in which to capture developmental changes in observed instances, rates, and facilitating factors of children's innovation. Moreover, it allowed for comparison with developmental studies of children's social learning.

Investigating innovation, or any phenomenon, requires a clear understanding and operationalisation of the behaviour to be studied. In Chapter 2 of this thesis, a new operational definition of innovation is formulated following an analysis of existing conceptualisations: "in the physical realm, a behavioural innovation is a new, useful and potentially transmitted learned behaviour, arising from asocial learning (innovation by independent invention) or a combination of asocial and social learning (innovation by modification), that is produced so as to successfully solve a novel problem or an existing problem in a novel manner." Explanation is provided in Chapter 2 for the components of this definition, why its formulation was required, and how it may facilitate future research. As referenced in the definition, however, this thesis focuses on physical innovations, and specifically those which occur in the tool-use domain. This has the obvious advantage of the direct observation and measurement of novel behaviour (that which has not been socially

observed or previously individually produced), and its permutations, whilst generating further knowledge of how humans are able to use, modify and produce expansive and diverse arrays of tools.

Tools are a ubiquitous component of human culture (Vaesen, 2012), and tool use “a vital component of the human behavioural repertoire” (Biro, Haslam, & Rutz, 2013, p.1). In its frequency, flexibility and complexity, human tool use is unique within the animal kingdom (Hunt, Gray, & Taylor, 2013; Kacelnik, 2009; Vaesen, 2012). The sheer volume of artefacts which we produce, and continuously engage with, is representative of the cumulative nature of human material culture and its exceptional sophistication. Early and competent tool use by human ancestors may have contributed to the evolution of intelligence (Kacelnik, 2009), whilst also raising individual fitness (Biro et al., 2013). Tool-use learning has been investigated extensively in social learning paradigms with children (following Want & Harris, 2002), which have aimed to understand its developmental process and the cognitive systems that differentiate humans from non-humans (Hernik & Csibra, 2009).

Human children begin to use and understand tools in accordance with their functionality from an early age (e.g., use of spoons by twelve months; Barrett, Davis, & Needham, 2007). From two years, children evidence advanced abilities in their rapid learning about novel tools, requiring in some instances only one exposure to a new artefact to categorise its function (Casler & Kelemen, 2005; Phillips, Seston, & Kelemen, 2012), as well as differentiating physically optimal and sub-optimal/non-functional tools (DiYanni & Kelemen, 2008; DiYanni, Nini, & Rheel, 2011). At four years, children possess ‘adult-like understanding’ of an artefact’s design (Kelemen, Seston, & Georges, 2012). Social learning (Hopper et al., 2010; Want & Harris, 2001; Whiten & Flynn, 2010), but perhaps not individual learning through manual

exploration (Gardiner, Bjorklund, Greif, & Gray, 2012), helps children infer required action plans and desired end states in their use of tools. Arguably the major difficulty for children when inventing tools is the absence of such information bridging start states (apparatus/materials) and end states (achieving a goal; Cutting, Apperly, Chappell, & Beck, 2014). Nevertheless, one can appreciate how exploration of existing tools will generate a deeper appreciation of “functional relationships between objects and the environment that would allow [children] to effectively wield tools to solve a variety of problems” (Gardiner et al., 2012, p.240); in other words, to innovate. ‘Flexible’ or ‘creative’ tool use viably requires both individual *and* social learning (Biro et al., 2013), necessitating their dual study.

With the benefits of early-emerging proficiency in tool use and understanding, there comes a cost. Categorising an artefact as ‘for’ a particular function means using that artefact in a way that was not initially intended by its design is difficult to entertain. This is known as ‘functional fixedness’: fixating upon the (demonstrated or learned) design function of an object as the proper, conventional or normative way to use it (Casler, Terziyan, & Greene, 2009; German & Barrett, 2005). Children appear motivated to gather function-based object information from preschool age (Casler et al., 2009). However, children are increasingly constrained with age (Defeyter, Avons, & German, 2007; DiYanni et al., 2011) such that ‘immunity’ to functional fixedness is granted to 5- but not 6- to 7-year-olds (Defeyter & German, 2003; German & Defeyter, 2000). Moreover, functional fixedness may be induced in 6- to 7-year-olds simply by demonstrating the ‘function’ of novel objects presented within the context of a problem-solving task (Defeyter & German, 2003).

Although this phenomenon has implications for imitation, it is of special relevance to innovation wherein the use of objects for a novel and alternative purpose is fundamental. Yet, rather than always being an obstacle to artefact innovation or innovative problem solving, knowledge of the functionality of artefacts may help to promote it. For Phillips et al. (2012, p.2057), “When consultation of tool category knowledge suggests a functional need is unmet within an existing repertoire of tools, recognition of this fact provokes people to innovate new tool categories that are designed to fulfil that specific purpose”. Moreover, recent research suggests that children are motivated, despite prior personal knowledge, to incorporate new tool-use task solutions into their behavioural repertoires rather than remain polarised to just one (Wood, Kendal, & Flynn, 2013, 2015). Examination of tool innovation in childhood, reviewed in Chapter 2, suggests that children are poor tool makers in the absence of social demonstrations (Beck et al., 2011; Hanus, Mendes, Tennie, & Call, 2011; Nielsen, 2013), irrespective of cultural background (Nielsen, Tomaselli, Mushin, & Whiten, 2014). When considering innovation in terms of population-level dynamics and its wider cultural contributions, however, we must also pay greater attention to innovation by modification (wherein social information is directly implicated). It remains to be seen how children fare when required to modify tool-use behaviour, as opposed to invent tools, and the primary difficulties they face, providing an imperative and further motivation for the current thesis.

1.3 Methods to Study Innovation

From the early observations of primate problem solving (Köhler, 1925), innovation has been met with interest by animal behaviour researchers (see Reader &

Laland, 2003). Their work has been instrumental in establishing that innovation is not only an adaptive mechanism (though, as with social learning, also has potential costs), in allowing animals to respond to novel challenges and threats, but one which is capable of wielding a strong evolutionary force, by way of its association with the brain evolution of birds (Overington, Morand-Ferron, Boogert, & Lefebvre, 2009) and primates (Reader, Hager, & Laland, 2011; Reader & Laland, 2002). More generally, however, findings from the different investigative methods they have employed provide much insight and inspiration for the study of innovation in humans.

Innovation in non-human animals is typically assessed by one of three routes: (1) the analysis of data within pre-existing (usually published) records and reports, (2) direct observation, and (3) experimental induction. Analyses of reported incidences of innovation have firmly instilled a conceptualisation of such behaviour as ‘novel’, ‘original’ and ‘never seen before’, with researchers using such search terms within large collated databases. This method has revealed incidence rates of innovation, across species and behavioural domains (including foraging and tool use), variation in innovation propensities due to sex, age and social rank differences (Reader & Laland, 2001), and relations with cognitive traits (Reader et al., 2011). As exploration of childhood innovation is in its infancy, there are few explicit studies from which data of this kind may be extracted and analysed (though currently an untapped source is the many investigations of children’s social learning wherein not all children opt to reproduce demonstrated behaviour).

The direct observation of animals within their natural habitat offers rich real-time data and external validity to the study of innovation. However, detection of innovations in the wild is often a lengthy practice and raises challenging issues in

terms of accurately determining the first instance of an innovative behaviour (achieved by van Schaik, van Noordwijk, & Wich, 2006). Given that innovation in the wild is largely evidenced by an individual solving a novel problem or an existing problem in a novel manner (in line with Kummer & Goodall's (1985) delineation of innovation), problem solving has become coupled with the innovation phenomenon. Indeed, the use of problem solving to investigate innovation has received recent empirical support owing to correspondence in their underlying mechanisms and factors that influence their appearance (Griffin & Guez, 2014). Open diffusion studies (Whiten & Mesoudi, 2008) offer the closest parallel to observation of natural innovation in humans, involving the introduction of a task to a group of freely interacting novices (e.g., Whiten & Flynn, 2010). Whilst studies of this kind are clearly well suited to examining children's innovation in ecologically-valid group settings (including how innovations spread and change, biases in transmission, and qualities of innovators and imitators), the research presented in this thesis employed a more controlled experimental method in combination with a dyadic design as is typical of social learning studies. Dyadic designs often involve, as in the current work, a knowledgeable adult experimenter and naïve participating child.

The experimental induction method evades the difficulties of long-term observation, providing a viable and widely utilised alternative of observing a species' innovative problem-solving ability via exposure to novel ecological and technical challenges (Benson-Amram, Weldele, & Holekamp, 2013; Kummer & Goodall, 1985). These challenges often take the form of novel extractive tool-based tasks, or 'artificial fruits' (Whiten, Custance, Gomez, Teixidor, & Bard, 1996), from which an individual must extract a reward by overcoming its defences. Artificial fruits have been used to great effect with humans and animals to explore social

learning and, increasingly, innovation, offering scope for multiple manipulations to address variables and questions of interest. With non-human species, these have included questions relating to the ‘properties’ or characteristics of innovators, inspiring the research of Chapter 4. As tools are implicated in everyday problem solving in many species (Bechtel, Jeschonek, & Pauen, 2013), their suitability in addressing questions of innovation, both practically and theoretically, is evident.

Implementing methodologies and tasks used with non-human animals, such as the hook task with New Caledonian crows (Weir, Chappell, & Kacelnik, 2002) and the floating peanut task with orangutans (Mendes, Hanus, & Call, 2007) in investigations of children’s innovation has been a successful strategy (e.g., Beck et al., 2011; Hanus et al., 2011). However, to date there is not a suitable existing tool-use task that would allow for a range of novel behaviours to be produced. Thus in this thesis a novel task, the Multiple-Methods Box, was created for the purpose of investigating children’s innovative behaviour following social demonstrations (innovation by modification) and in the absence of social demonstrations (innovation by novel invention). In each case, children were provided with multiple attempt trials (opportunities to interact with the task), both to mirror the artefact learning process and to observe behavioural change, such as switching from imitation to innovation.

1.4 Thesis Aims and Format

Innovation is an understudied area within developmental psychology. Many important questions concerning its appearance, development, individual variation, and cognitive or contextual facilitators remain to be addressed. This thesis aimed to advance such knowledge of children’s innovation in the physical, tool-use domain.

In the absence of an agreed-upon definition, Chapter 2 overviews existing theoretical, non-human animal and human developmental research to offer a working definition of behavioural innovation and criteria for its identification. In doing so, innovation is carefully separated from other related constructs such as exploration and creativity and a common ‘language’ established with which to discuss innovation. Along with a working definition, this chapter provides a hypothetical pathway to innovation (a starting point for considering how the innovation process is facilitated and constrained) and an innovation classification system (distinguishing different ‘levels’ of innovation and their cultural implications).

This is followed in Chapter 3 by the first empirical study of children’s innovation by modification (as opposed to innovation by novel invention) in the context of a novel tool-use task (the Multiple-Methods Box; MMB). In the light of adaptive informational trade-offs in the use of social and personal (individual) information by non-humans, and children’s rational and flexible social learning, this study aimed to examine when children judge it futile to imitate and thus opt to *innovate* when given sufficient opportunity and means to do so. Although innovation was found to be a rare response for 4- to 9-year-old children (when compared with imitation) following social demonstrations of a task solution, increased innovation was found in response to lower levels of observed solution efficacy. Moreover, important developmental changes in imitation (decreasing from 6-7 years) and innovation (increasing from 8-9 years) were discovered. Children’s prioritisation of social information is discussed in relation to the known adaptive functions of social learning, the rarity of innovators in theoretical models of cultural evolution, and the difficulties of overriding socially-acquired information. As a small subset of children in this study distinguished themselves from their peers by innovating, questions

naturally arose regarding what may have set them apart. With the purpose of identifying and assessing factors that may underpin individual differences in children's behavioural innovation, the research of Chapter 4 involved following up children identified as innovators or imitators in Chapter 3 and administering a range of tasks assessing constructs of theoretical and/or empirical relevance to innovation. Whilst the results indicated some behavioural consistency in children's performance on puzzle-box tasks, the overall lack of innovator-imitator group differences suggested that, in such contexts, an individual's 'state' may play a greater role than personality 'traits' in eliciting innovation.

The final two empirical studies, contained in Chapters 5 and 6, set out to test two possible interventions to promote appearances of innovation in children. Recognising that cues to conventionality of behaviour typically serve to promote imitation and reduce innovation, the first intervention study (Chapter 5) hypothesised that framing innovation as a normative behaviour may help to foster its occurrence. Verbal frames providing 'positive' or 'negative' information regarding the conventional performance of peers on the MMB (the number of different ways other children had purportedly found to extract rewards) did not, however, differentially affect innovative performance. This hinted at the operation of alternative individually-driven motives to complete the task. The second intervention (Chapter 6) stemmed from an acknowledged need for more ecologically-valid experimental approaches that provide sufficient timeframes and space in which innovation can be evidenced. Children who had previously received social information and acquired personal experience with the MMB task (Chapter 3) were permitted additional, verbally-prompted, attempts with the task in a second phase. Increased instances and rates of both exploration and innovation were observed, indicative of a facilitatory

role of increased time and opportunity to explore the box along with explicit instructions and prompts to do so. The thesis concludes in Chapter 7 with a discussion of the implications of the thesis findings for an understanding of innovation from cognitive, developmental and cultural evolutionary perspectives. Here, avenues for future research are offered, and reflections made on the pathway to innovation presented in Chapter 2 in the light of the findings in this thesis.

The chapters presented in this thesis are in publication manuscript format. References are presented at the end of the corresponding chapter.

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Chapter 2

Eureka!: What is innovation, how does it develop and who does it?

Abstract

Innovation is not only central to changes in traditional practice, but arguably responsible for humanity's remarkable success at colonising the earth and diversifying the products, technologies and systems within it. Surprisingly little is known of how this integral component of behavioural flexibility develops, and the factors that are responsible for individual differences therein. This review highlights two primary ways in which the process and development of innovation may be better understood: by emulating the critical advances of animal behaviour researchers in examining innovation in non-human species, and establishing a clearer conceptualisation of what is 'innovation'. A pathway to innovation is suggested and an innovation classification system offered, to aid recognition of its appearance and potential cultural contributions.

2.1 Introduction

Around 70,000 to 80,000 years ago, in the African Middle Stone Age, technological and behavioural innovations suggestive of modern human capacities appeared (Mellars, 2005). Although the widespread emergence of complex human culture is typically ascribed to the later developments of the European Upper Paleolithic (Shennan, 2001), there is little doubt that humanity's creative revolution sparked some tens of thousands of years ago (long after the earliest displays of hominin tool use, estimated 2.6-1.4 million years ago; see Nielsen, 2012).

Advances in human cognition over evolutionary history have engendered inventions and innovations of such sophistication, and complexity, that they surpass those of all other non-human species. Whether fuelled by one factor or a combination, including brain evolution, demography or social network size, climate change, emergence of language and cooperation (e.g., Elias, 2012), it is irrefutable that humans have creatively and culturally excelled. Given its critical importance to our success, it is surprising that our understanding of innovation in humans, including its evolutionary foundations, developmental trajectory and contextual facilitators, is still in its infancy. As such, developmental psychologists have much to contribute to the innovation discussion and much to gain.

2.2 Innovation

2.2.1 Placing Developmental Psychology on the Stage of Innovation Research

There is a rich history, across academic disciplines, of applying the concepts, theories and empirical advances of one field of study to another. Here, we aim to draw together knowledge from comparative psychology, developmental psychology and animal behaviour research to contend, as Want and Harris (2002) did in relation to the social learning of tool use, that the much-needed dedicated developmental study of innovation may be informed and accelerated by an analysis of research elsewhere. Though this analysis needs to be applied to all aspects of study, including research questions, techniques, tasks and findings, here our primary goal is developing an agreed-upon definition. An essential first step in advancing our understanding of innovation is determining precisely what is meant by this term. A clear definition will aid in decisions about, (i) who we conceptualise as innovators, (ii) the form of behaviour labelled as innovation, (iii) the frequency of innovation, and (iv) the contribution innovation makes to cumulative culture (a major discussion point in the ensuing sections). The current lack of operationalisation within developmental psychology, in contrast to work within the animal behaviour field, may be impeding research progress by preventing the establishment of a common ‘language’ with which to discuss innovation; a language which carefully separates innovation from related yet conceptually and cognitively distinct constructs, uses similar terminology and criteria for identification (depending upon the ‘form’ that it takes; see Section 2.3.1, point i), and resists human-centricity such that comparisons with other species can be made. Achieving greater consistency in terminology use,

by delineating terms associated, but not synonymous, with innovation, and increasing collaboration between developmental and comparative researchers, is therefore imperative.

Childhood innovations appear in a number of domains: games, pretend play, drawing, storytelling, and more general language. In this article, we focus on *behavioural* innovation in the physical domain, specifically novel problem solving in the context of tool use. We do so for several reasons. Firstly, novel objects, in the form of artifacts and tools, saturate our world, and we must understand and use an enormous array of them from a very early age. If “learning to use tools and artifacts is inextricably linked to the developmental study of *imitation*” (Carpenter & Nielsen, 2008, p.225, emphasis added), then their invention or modification is inextricably linked to the developmental study of *innovation*. Secondly, in pursuing a working definition for developmental psychologists, we are mindful of the need for innovation to be a “useful and usable concept” (Reader & Laland, 2003, p.11); that is, one which affords transparency in meaning and with which researchers can theoretically and experimentally engage. An overarching definition is desirable, but how the innovation phenomenon is expressed between domains may be diverse. Hence, a narrowing of focus to the physical domain is necessary in this case. Finally, there is a wealth of tool innovation research with non-human animals from which knowledge may be drawn and critical cross-species comparisons made. This aids understanding of the phylogenetic (evolutionary) development of innovation and helps uncover phylogenetic relationships, uniqueness and origins of abilities, the influence of culture, language, and so on.

An important question to address is why it is necessary to bring questions about innovation to the developmental field. Crucially, compared to research on

social learning (e.g., special issues in *Journal of Experimental Child Psychology*, 2008; *Philosophical Transactions of the Royal Society B.*, 2009; *Developmental Psychology*, 2013), the development of innovation in humans has received little attention. However, innovation and social learning may be regarded as two sides of the same coin, closely related in terms of their likely underlying mechanisms (Heyes, 2012) and their complementary roles in the acquisition, transmission and evolution of culture, meaning insights into one will be highly informative for the other. Furthermore, adaptive trade-offs operate between the two (Kendal, Coolen, van Bergen, & Laland, 2005) such that observing when children innovate will help reveal the conditions under which they judge *imitation* a comparatively less effective learning strategy (addressing a ‘why’ question of innovation). It makes little sense, therefore, to know so much about one side of the coin (social learning) and so little about the other (innovation).

In general, observations of ‘innovative’ behaviour (in the sense of non-copying) within the social learning literature have largely been treated as secondary or anomalous findings and thus not pursued. The lack of innovation research may be due to the rarity with which children deviate from social information in experimental contexts and, in turn, produce novel behaviour. This is compounded by the lack of opportunity for innovation in social learning studies given they are not designed to afford this. Importantly, infrequency does not equate to incapability. Furthering our understanding of how, and why, innovation operates ontogenetically (develops over time in an individual) is essential to understanding its typical trajectory, behavioural manifestations, mechanisms, relations with other aspects of cognition (constituent processes such as exploration, play, tool use and problem solving in the case of physical cognition), individual differences in ‘innovativeness’, and ultimately how it

may be enhanced (see also Chappell et al., 2015). Comparing innovative propensities across age groups will prove fundamental to establishing the developmental factors that impact upon innovation across the lifespan. Developmental changes in imitation (including ‘over-imitation’), normativity, functional fixedness, and cognitive flexibility are such potential influencing factors.

First we reflect on the importance of innovation from the wider perspective of cultural evolution, demonstrating the need for a deeper understanding from developmental psychology of the development of and requirements for innovation. In Section 2.3 (‘Identifying Innovations’) we draw upon theoretical and non-human animal research to present an overview of the requirements for innovation, and construct a theoretical pathway to innovation. In Section 2.4 (‘Theoretical Contributions’), we formulate an operational definition of innovation and an accompanying classification system. We close in Section 2.5 (‘Conclusion and Future Directions’) by proposing future avenues for research.

2.2.2 The Cultural and Evolutionary Importance of Innovation

Cultural innovation is to cultural evolution what mutation is to biological evolution: without innovation, cultural traits and therefore cultural transmission would not exist.

Biologists Lehmann, Feldman and Kaeuffer (2010, p.2356) perfectly summarize the critical nature of innovation within cultural evolution. Innovations, whether products, actions or behaviour, have not only aided in the generation of cultures (group-typical behaviour patterns, shared by members of (animal)

communities, that are to some degree reliant on socially learned and transmitted information; Laland & Janik, 2006, p.542), but more elaborate cultural systems wherein knowledge is repeatedly built upon and products and practices progressively modified and improved. The repeated modification of cultural traits, increasing the trait's complexity or efficiency, is the hallmark of a *cumulative* culture (Dean, Vale, Laland, Flynn, & Kendal, 2013). Technological innovations, in particular, are often not the output of any single individual, but the result of collective and incremental efforts over time. Concepts, ideas and discoveries of predecessors inform problems anew, such that designs may be honed, flaws corrected and efficiency increased. Such 'cultural ratcheting' (Tennie, Call, & Tomasello, 2009) would not be possible in the absence of high fidelity social learning (e.g., imitation, innovation's cultural counterpart), enabling the intergenerational preservation of knowledge and the transmission of innovated modifications (Boyd & Richerson, 1985). These processes are intricately entwined; indeed, "the transmission process itself can be a continuous creator of innovation" (O'Brien & Shennan, 2010, p.8). Together, innovation and high-fidelity transmission establish traditions, afford cultural products the opportunity to proliferate and evolve, and are likely candidates in the search for what makes our species, and our capacity for cumulative culture, so unique (Dean et al., 2013).

The above is, of course, an oversimplification of the development and maintenance of cultural systems, insofar as not all innovations are 'good' (i.e., solve problems or increase efficiency) nor are all 'good' innovations adopted. It is beyond the scope of this article to unpack the complexities of how cultural systems evolve, but we acknowledge that change will not inevitably ratchet 'up' sophistication and efficiency (of a technology or behaviour). Moreover, as different cultural traits enjoy

different levels of success and longevity, considering *resistance* to innovations is just as important as their adoption and transmission.

Whilst this review ultimately provides an individual-level definition of innovation, it is impossible to detach discussion of individual innovations from discussion of cultural innovations. This is because when assessing the impact or adaptive value of an innovation, it is more difficult (and subjective) when that innovation belongs to a sole individual. What may be adaptive to one individual may be non- or maladaptive to another, depending upon one's criteria. Certainly, the value of an individual innovation is easier to infer when its usefulness or efficiency is readily apparent. However, a more objective measure of an innovation's adaptive value, or capacity to induce change, is the degree to which it is a cultural innovation in being transmitted to other individuals (see Section 2.3.1, point vi).

In theory, the adaptive benefits of an individual-level innovation may be vast. To innovate is to potentially maximise exploitable resources, increase the efficacy of one's behaviour and circumvent novel challenges and threats. By allowing individuals to better adapt and respond to changing environments, innovation maximises survival. In a positive feedback loop, novel behaviour favors more able individuals, creating selection pressures for brain areas responsible for complex technical behaviour (Reader & Laland, 2002) and, in turn, favoring the emergence of yet more complex behaviour. Indeed, greater numbers and diversity of technical innovations are implicated in the evolution of brain size in birds (Overington, Morand-Ferron, Boogert, & Lefebvre, 2009) and primates (Reader, Hager, & Laland, 2011). As with social learning, however, there are costs to the indiscriminate use of a learning strategy. Innovation must be considered most adaptive when flexibly utilised (Toelch, Bruce, Meeus, & Reader, 2011). Moreover, deviating from

established behaviour is inherently risky, meaning “a certain level of hesitancy to adopting novel behaviors is warranted” (Brosnan & Hopper, 2014, p.1).

2.3 Identifying Innovations

Innovation definitions and delineations from the animal behaviour field have abounded in recent years. Reader and Laland’s (2003) comprehensive appraisal of the animal innovation literature formulated two widely-cited definitions of the phenomenon: (a) an innovation (*sensu* product) is a new or modified learned behaviour not previously found in the population, and (b) innovation (*sensu* process) results in new or modified learned behaviour and introduces novel behavioural variants into a population’s repertoire. While there is no surer way of determining innovation than if it has never before been seen in a population, this definition raised the expectation of long-term monitoring in order to observe behavioural origins (which, while challenging, some have met; van Schaik, van Noordwijk, & Wich, 2006). Ramsey, Bastian and van Schaik (2007) conversely endorsed the view that ‘Innovation is the process that generates *in an individual* a novel learned behaviour’ (p.393, emphasis added). Determining the level at which to pitch innovation for developmental research is one of several reasons why it would not be appropriate to simply adopt existing definitions. As with applying the particular methods of animal behaviour researchers, it is important to consider how requirements for innovation translate between species.

To fully understand the evolution, development, consistency and extensiveness of children’s innovation, a clear definition, workable across a variety of contexts, is needed. The shortage of developmental work necessitates that, in our

journey towards a definition, we reflect upon alternative bodies of literature (including animal and human adult). However, the focus remains on its relevance and applicability to childhood and development.

2.3.1 Markers of Childhood Innovation

Childhood is a time of exploration, play and learning. The potential to discover and produce unusual or novel behaviour is vast. Are each of these occurrences to be considered an innovation? We think not. There are criteria which a potential innovation must meet, and this forms the basis of both the ensuing discussion and our innovation definition (see Section 2.4).

- i. Innovation can be the result of asocial learning or a combination of asocial and social learning, but it must be novel.

At the upper-most level of distinction, learning may be social (information is acquired from others), asocial/individual (independent of social observation or interaction), or a combination of the two. Whilst innovation may be considered “largely asocial learning” (Kendal, Giraldeau, & Laland, 2009, p.218), in that the innovator ultimately produces behaviour that has not, in its full form, been socially observed, it is often an evaluation of information acquired socially that induces innovation; specifically, judging “that a novel solution to a problem generates superior returns than does an established (observed) behaviour” (Laland, 2004, p.10, parentheses added). It is not, therefore, technically independent of any social influence. This leads us to our proposition that innovation is not wholly asocial (nor,

indeed, is all asocial learning innovation). Thus it is advantageous to assign beneath the ‘innovation’ umbrella the terms of *independent invention* when novel behaviour results from asocial learning, and *modification* when social influences are directly implicated (as in cumulative culture). There are two main reasons why we believe this distinction to be advantageous, both of which are revisited later in this section. First, the two forms may have different cognitive underpinnings and different developmental profiles, meaning inferences or generalisations about children’s abilities cannot be made on the basis of the assessment of only one form. Second, they likely contribute differently to processes of cumulative culture and cultural transmission, partially as a result of the primary source of information from which they draw.

Note that in the case of independent invention, we do not refute that individuals will be equipped with some social information acquired from prior interactions and experiences with the world (e.g., in inventing a novel tool, the components that make up the tool may not themselves be novel), including products of others’ behaviour. Rather, what we aim to distinguish is whether asocial learning is the predominant learning mechanism involved in producing the innovation (there is no immediate social learning from which the impetus for the innovation directly emerges, as with innovation by modification). Making this distinction will not always be straightforward, and indeed becomes blurred when ‘goal emulation’, where the means of achieving a socially-observed goal is arrived at through a different means, may be considered innovation by invention or modification (see point v). Nevertheless, the idea that independent invention should be regarded as one form of innovation, i.e., a clear derivative of asocial/individual learning, has

theoretical support (e.g., Kandler & Laland, 2009; Lewis & Laland, 2012; Slater & Lachlan, 2003).

Human tool use is, in its frequency, flexibility and complexity, unique within the animal kingdom (Kacelnik, 2009). Tool-use learning has been extensively investigated in social learning paradigms, designed to understand the age at which children become proficient tool users, the factors that enable it, and the cognitive systems that differentiate humans from non-humans. Tool-use learning has similar potential to inform and direct investigations of children's innovation. Although few in number, examinations of tool-use innovation in children have revealed one consistent finding: children are poor innovators. Hanus, Mendes, Tennie and Call (2011) compared apes and human children in a 'floating peanut' task in which water had to be used as a tool to retrieve a peanut from the bottom of a narrow tube. The developmental progression in children's success was marked, with only 8% of 4-year-olds but 58% of 8-year-olds succeeding. The authors attributed this to the greater cognitive flexibility of the older children, facilitating their abandonment of ineffective methods, together with their enhanced exploration, insight and attention to alternative task components. Nielsen (2013) replicated the finding that 4-year-olds experience great difficulty producing the necessary innovative behaviour in the floating object task, yet acquire the solution immediately following the demonstration of a knowledgeable adult. Hence the problem is not one of performance, but identification and generation of the required response.

In a similar reflection on comparative literature, Beck, Apperly, Chappell, Guthrie, and Cutting (2011) presented 3 to 11 year old children with a task originally used with New Caledonian crows. The task required manufacturing a novel tool (a hook from a pipe-cleaner) to extract a bucket from a tube. As in Nielsen's study, tool

innovation was difficult for the youngest children and success increased with age. Task variations including tool preference selection and prior object manipulation did not impact upon performance. A social demonstration, however, permitted nearly all children to succeed. The ‘ill-structured’ nature of tool innovation problems was offered as an account for the findings, with the absence of clearly defined strategies for moving between the starting conditions and goal states theorised to impede progress. A recent study employing the same task to compare Western and Bushman children, aged between 3 and 5 years, further suggests that cognitive limitations underlie innovation difficulties (Nielsen, Tomaselli, Mushin, & Whiten, 2014). Somewhat surprisingly, despite vast differences in cultural environments and exposure to pre-made artifacts, both groups evidenced similarly poor tool innovation. Further research into how the capacity for innovation emerges (precisely which cognitive factors are implicated) will only be possible by continuing developmental investigations of this kind.

According to our delineation, these studies examine innovation by independent invention but not innovation by modification. Their importance cannot be disputed: novel problem-solving tasks offer a highly suitable means to reflect upon children’s capacity for novel invention. Asocial control participants of social learning studies offer similar insight. The invention-modification distinction may not be universally accepted as a necessary one, but we nonetheless believe it has utility. There are reasons to believe that the two forms of innovation will have different primary difficulties associated with them, potentially altering their developmental profile. Whereas the ill-structured nature of problems proves challenging for novel invention tasks, an ontogenetic imitation bias induced by social information (e.g., Horner & Whiten, 2005) is highly likely to prove equally challenging for

modification tasks by impacting the generation of alternate *asocial* output (Wood, Kendal, & Flynn, 2013).

With regard to capacities for cumulative culture, tasks must permit opportunities for modification, refinement and/or recombination of established behaviour in order to mirror the ratcheting process. One serendipitous, but influential, invention may outweigh iterative alterations when it comes to cultural diversity (Kandler & Laland, 2009), but novel invention is of lesser consequence for cumulative culture (Lewis & Laland, 2012). These theoretical findings support the deconstruction of innovation (for both definition and study), owing to the wider cultural implications of innovation's various forms.

Irrespective of the form it takes, the concept of innovation is tied to that of novelty (Reader & Laland, 2003). Given that we already have opposing views of population- and individual-level novelty in the animal literature, how is novelty to be judged? In experimental research, by introducing novel tasks we are able to say that any behaviour exhibited, that has not previously been socially observed (in its full form), is indeed new *to that individual*. Where tasks are posed in group contexts, the first 'solver' meets the population-level definition of an innovator (producing behaviour not previously found in the 'population'), along with any individual who introduces a new solution (whether completely new or a combination or modification of observed behaviour: Flynn & Whiten, 2012; Whiten & Flynn, 2010). Since almost every new behaviour resembles, if not contains, existing behavioural constituents, a strict definition of novelty would be unwise. In the animal literature (following Kummer & Goodall, 1985), innovation is additionally assessed in the light of the *context* in which the behaviour is performed. Thus either the innovation-inducing problem (necessitating use of novel or existing behaviour patterns) or the solution to

an existing problem may be novel (again, without the basic behavioural and motor elements necessarily being so).

- ii. There are a number of hypothesised contributors or precursors to the innovation process. These include, but are not limited to, causal understanding, insight, curiosity, exploration (discovery learning), divergent thinking, and creativity. They do not equate to innovation, and alone are not sufficient to produce it.

Just as imitation, emulation, mimicry and enhancement learning possess commonalities, requiring specific experimental designs to delineate them, so innovation shares elements of its process and product with other related constructs. Particularly in their combination, these constructs facilitate higher-level cognition thereby promoting the cognitive maturation plausibly conducive to innovation.

Causal understanding denotes an appreciation of the causal relation underpinning a covariance. Knowing what causes something means knowing how it may be changed, and this is central to humanity's technological achievements (Vaesen, 2012). Deducing causal understanding from the production of an innovation is met with caution by some animal researchers, particularly when innovative problem solving 'may be more parsimoniously explained by simple, conserved associative processes' (Thornton & Samson, 2012, p.1466). Causal knowledge does, however, play an important role in human ontogeny, and specifically cognitive development. Within the first two years of life, causal learning is evident in children's interpretations of events (Walker & Gopnik, 2014) and by the fifth year, causal-based inductions direct children's category-based reasoning (Hayes

& Thompson, 2007). While simple causal understanding does not require high-level reasoning abilities, it may be that the latter better facilitates the innovation process. It is also necessary to consider the relation between task difficulty and causal understanding development: younger children may have sufficient causal knowledge to innovate on simpler tasks, but not more complex ones. Flexible inductive reasoning, wherein a variety of inferences may be made about a single item that fits multiple categories, develops throughout childhood (e.g., Bright & Feeney, 2014). Such sophisticated reasoning, involving the consideration of multiple possible outcomes, may allow children to better evaluate the employment of social and/or asocial information, and consequently utilise innovation when it is most appropriate.

Insight, defined as “the sudden production of new adaptive responses not arrived at by trial behavior... or the solution to a problem by the sudden adaptive reorganization of experience” (Thorpe, 1964, p.110), may also play a role in the innovation process. We note, however, that if one accepts innovations need not possess intentionality (point vii) and may arise accidentally, insight need not be implicated. For Kacelnik (2009, p.10072), “Even in humans, the causal use of the term insight is ridden with difficulties, and it can hardly be claimed to explain much”. We remain uncertain regarding how much emphasis should be placed upon insight; it clearly has some role in certain forms of novel behaviour, but does not encapsulate all instances of novel problem-solving and, further, is very difficult to determine.

Outwardly, **curiosity** appears a more neutral and less contested term to impart. It captures an individual’s motivation to discover and learn more about the environment. Being curious acts to prompt exploration. Yet, as with insight, there is also the implication of foresight (Hauser, 2003): a reason to be curious in the first

place ('what does this do, and why?'). There obviously exist objects which promote curiosity, a prime example of which are artificial fruit tasks, widely used by developmental psychologists and in animal behaviour research (e.g., Horner & Whiten, 2005). They contain the motivation (food reward) for animals to interact with and explore artifacts.

A concept closely tied to curiosity is **exploration**; clearly, trying to work out ways in which to do something differently requires exploratory testing of ideas, paving the way for innovation (Sol, Griffin, Bartomeus, & Boyce, 2011). Remarkable advances have been made in understanding how children's exploratory play allows them to formulate theories of, and learn about, the world. In using play to test hypotheses and generate causal knowledge, they may be viewed as 'like' scientists (Gopnik, 2012). Importantly, play provides children with information about the functionality of objects that, if not immediately relevant, may have future use. Animals also play, but the key difference for our own species is pretense. Pretense as a specific form of play, wherein individuals generate and reason with imagined (often novel) scenarios and objects, has been touted as a springboard for innovation through its promotion of creativity (Nielsen, 2012; Picciuto & Carruthers, 2012). The evolutionary function of pretend play is, indeed, considered to be the practice of creative thought (Carruthers, 2002).

Exploration, whether inside or outside of an imagined setting, can promote new learning, contributing to an appreciation of how behaving in a novel manner may yield different, perhaps more efficient outcomes. The significance of age in a discussion of innovative tendencies is tied to the question of how much an individual may benefit from greater, and more diverse, exploration. That is, recognising that a new response is required and physically producing one may require the competence

and experience of adulthood (Kendal, Coe, & Laland, 2005). Though certainly related, exploration is *qualitatively distinct* to innovation (Reader & Laland, 2003): you may explore, but you may not always innovate.

A number of predictions may be made regarding the interplay between exploration and familiarity (or expertise) in a given domain. Exploration is certainly likely to increase familiarity, but what of the reverse effect? Simonton (2000) notes, when considering creative achievement, that domain-relevant experiences are of importance. Though there is variability and a number of factors that feed into the relation, it appears that cumulative experience within a domain enhances creative impact. There is, therefore, an argument to be made that familiarity will prompt more directed exploration and increase the likelihood of innovation production. However, the nature of prior experience in a domain will viably make it more or less likely that an individual is motivated to explore. They may be less willing to consider alternative behaviour if their prior experiences are associated with some negative consequence. Moreover, familiarity can also heighten functional fixedness and conservatism (point iii).

Exploration is particularly potent in its combination with **divergent thinking** (essentially the opposite of functional fixedness). Divergent thinking denotes the ability to search for new ideas (Guildford, 1959, as cited in Bijvoet-van den Berg & Hoicka, 2014), and is thus implicated not only in problem solving but in creative potential and productivity (Runco & Acar, 2012). Even at 2 years of age, children demonstrate individual differences in divergent thinking, with evidence to suggest that greater exploration (producing a variety of actions on a novel object) is linked with originality (Bijvoet-van den Berg & Hoicka, 2014). Whilst originality links divergent thinking and creativity (and innovation), they are not synonymous; one can

demonstrate good divergent thinking without demonstrating creativity (Runco & Acar, 2012). Conceiving multiple potential solutions to a puzzle does not imply they will be good, useful or workable (Runco & Acar, 2012). In contrast, typical definitions of **creativity** require that creative ideas, behaviour and problem solving be both original *and* valuable (Picciuto & Carruthers, 2012). One's perspective regarding *to whom* these must be valuable inevitably alters the goalposts of creativity.

Many relevant ideas regarding the innovation-creativity distinction are offered by Levitt (1963). Principally, creative thoughts are regarded as a precipitating factor for innovation but must undergo conversion to qualify as such. It is the difference between generating ideas and implementing them: the abstract versus the concrete. This is a common distinction made in business, but one that is consistent with Simonton's (2003, p.311) conceptualisation of innovation as "the end product of a creative process".

From this discussion, we have formulated a hypothetical pathway to innovation (Figure 2.1). We tentatively offer this pathway as a starting point, with the hope it will stimulate debate and be improved upon by subsequent research. By presenting the precursors to innovation, we also hope it may serve as a useful theoretical framework for educators, and individuals in various sectors, who wish to consider ways to promote the innovation process.

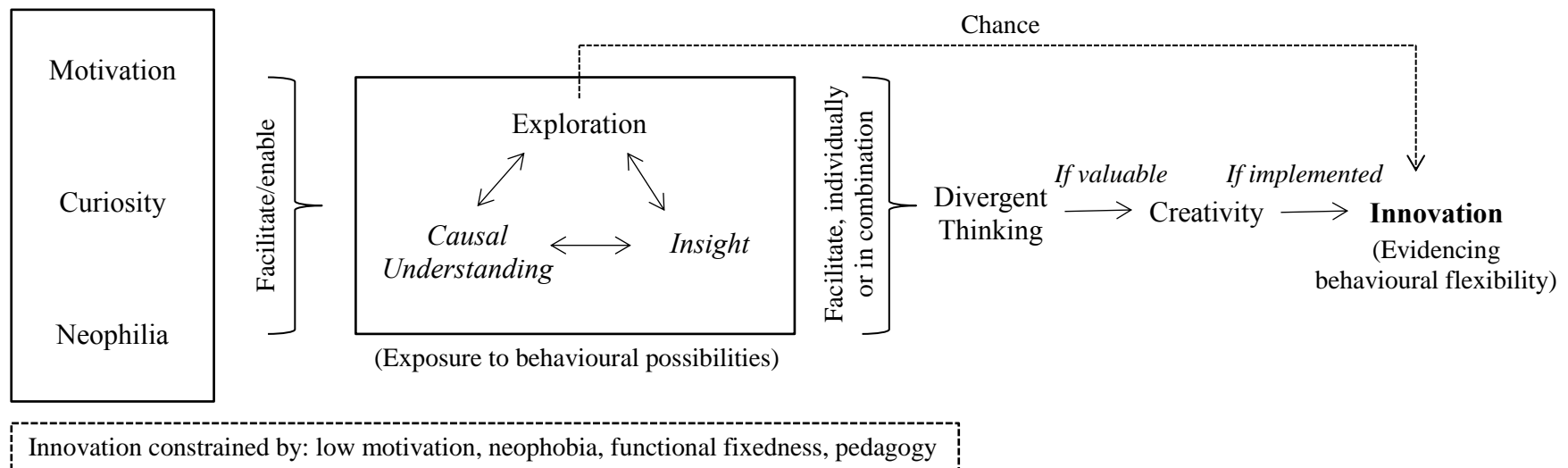


Figure 2.1. A hypothetical individual-level pathway to innovation. Arrows denote which construct leads to another construct. From left to right, any of the processes within the first block can lead to those within the second block. The constructs in italic text within the second block play more contested, or less direct, roles in this pathway (see point ii). Neophilia, and its opposing construct neophobia, are discussed in point iii. Context and prior learning (social and/or asocial) are acknowledged to potentially contribute to each construct portrayed and to differentially promote behavioural change. Innovation is generally regarded as a component of behavioural flexibility, by allowing “individuals to react to environmental changes... [by] changing established behavior” (Toelch et al., 2011, p.1). It should be noted that, rather than necessarily prompting divergent thinking and creativity, exploration may allow an individual to stumble upon an innovation by chance, captured by the connecting arrow.

- iii. Functional fixedness (conservatism), low motivation, pedagogy, and neophobia restrict innovation.

Functional fixedness, or behavioural conservatism, is a likely inhibitory factor in innovation. It denotes fixation upon the demonstrated or learned design function of an object as the proper, conventional or normative way to use it. Children attain such a concept of artifact function at around 6 or 7 years of age (Defeyter & German, 2003), prior to which time they ostensibly possess greater flexibility in artifact use. The development of functional fixedness impacts innovation: categorising an object as ‘for’ a particular function means using it in a way not initially intended by its design, as is often required in tool innovation and novel problem solving, is difficult and serves to compound the imitation bias. Younger children may be more ‘immune’ to functional fixedness (it affects 7-year-olds to a greater extent than 5-year-olds; Defeyter, Avons, & German, 2007), but disadvantaged by more general cognitive immaturity. Discovering ways to reduce its effects will plausibly enhance children’s developing capacity for innovation. Due to its combination with artifacts, functional fixedness is a unique problem when studying innovation within the context of tool use. Investigations outside of this domain will only prove complementary and extend our understanding of when and why children experience difficulties.

As expected, **motivation** is closely tied to innovation propensity (Reader & Laland, 2003). Whether arising from factors in the environment, such as a food reward, or from a stable individual motivational component to discover more (Sol, Griffin, & Bartomeus, 2012), it can be viewed as a necessary starting constituent of the innovation process, prompting exploration. The understanding and knowledge

that can be ascertained through exploring the environment makes **pedagogy**¹ (explicit direction or teaching) a ‘double-edged sword’: in the same way as observation (Wood et al., 2013), it leads to efficient, but restricted, exploration and learning in preschoolers (Bonawitz et al., 2011).

Open diffusion studies, involving the introduction of a model and task to a group of freely interacting novices, have provided opportunities to reflect upon biographic, social, cognitive, and temperament predictors of social learning (Flynn & Whiten, 2012). Specifically, increasing age, popularity, dominance and impulsivity have been seen to promote children’s successful interactions with a foraging apparatus. Animal studies have found the predictors of *innovation* (here, successful novel problem solving or foraging) to include exploration, neophilia - being novelty-inclined or unafraid to approach or interact with new objects - and persistence (e.g., Benson-Amram & Holekamp, 2012; Thornton & Samson, 2012). **Neophobia**, the fear of novelty, conversely acts to restrict exploration intensity (Sol et al., 2012) and thereby plausibly innovation. Certain social factors, such as the presence of conspecifics (Griffin, Lermite, Perea, & Guez, 2013), appear to similarly deter innovative foraging in animals. This latter research demonstrates the need to consider extrinsic, as well as intrinsic, influences on the expression of innovation. Given the heightened social motivations of children, and humans more generally, social and contextual factors will have a large role to play in an individual’s decision to deviate from established behaviour.

¹ Pedagogy is used throughout this thesis in line with Csibra and Gergely’s (2009, p.148) conception of *natural* pedagogy (“the specific aspects of human communication that allow and facilitate the transfer of generic knowledge to novices”). Ostensive demonstrations, which feature in the experimental work throughout, are a component of natural pedagogy by virtue of the signals or cues (including eye contact and directed speech) that are suggestive of intentional communication or teaching.

- iv. Innovations, being of multiple origins, may be cognitively distinguished.

A number of potential sources of innovation have been identified, all of which are deemed capable of introducing new cultural variation into a population. These include, as listed by Mesoudi et al. (2013), chance factors (i.e., accidents and copying errors), novel invention (be it through trial-and-error, insight, or exploration), refinement (modification and improvement), recombination (of behavioural variants), and exaptation (the application of behaviour to a new function). The implication is that innovations are not equal: although the end products may look remarkably similar, the processes from which they have arisen may differ. What is important for innovation classification is that, in each case, independent of source, the behavioural outcome is recognised as viable and useful. These judgments will not be free of subjectivity.

Recognition of innovation sources has led to the categorisation of ‘types’ of innovation, potentially impacting upon their study and measurement. In accordance with Ramsey et al. (2007) who endorse a ‘cognitively simple’ and ‘cognitively complex’ innovation distinction, Rendell, Hoppitt, and Kendal (2007) refer to ‘passive’ and ‘active’ innovations with the former in both cases involving chance factors. In a study examining the social learning and innovative propensities of common marmosets, Burkart, Strasser and Foglia (2009) offered a similar operationalisation; Type I innovations correspond closely to common conceptions of innovation involving goal-directed and problem-induced behaviour, and Type II innovations, in contrast, are characterised as more incidental, and plausibly accidental, arising not due to the need for a solution to a problem but as a result of situations offering chance, and scope for, novel behaviours. Thus authors include an

idea of weak and strong innovations, the latter denoting active ‘thinking up’ of novel behaviour and resonating with typical definitions of fluid intelligence (including the ability to solve novel problems). The developmental trajectories of these two types of innovations may be distinct. One could hypothesise that Type I (‘active’ innovations) will be more prevalent in late rather than early childhood, when individuals are equipped with greater experience and cognitive maturity. However, as we discuss in relation to intentionality (see point vii, and Section 2.4), we believe the emphasis should be more upon subsequent learning.

For some, there is no value in identifying the origin of an innovation; the “ecological and evolutionary consequences of innovation need not depend on the cognitive sophistication of the innovative process” (Laland & Reader, 2010, p.41). It may not be so much genius that underpins innovation as chance (Lewis & Laland, 2012). However, where an innovation occurs by chance, it may not be learned, thus not repeated and consequently neither useful nor influential in terms of cultural transmission and traditions (Reader & Laland, 2003).

- v. Goal emulation can represent a weak form of innovation.

Emulation involves learning about object properties, affordances and causal relations (Want & Harris, 2002). Affordance learning, one form of emulation, may be observed in ghost control experiments wherein the movements of an apparatus are demonstrated via hidden mechanisms, in the absence of a live model or agent. By matching the ghost demonstration, individuals evidence learning about the affordances of the action(s) and the properties of an object (beyond simple object movement re-enactment). In goal emulation, the observer reproduces the model’s

goal but uses their own method (e.g., selecting a different tool). But what if, in this instance, the individual opts for an individually-discovered *novel* method, involving the use of a novel tool for example? It may not be novel problem solving, but it *is* finding ‘a new solution to an old problem’. Whether this new solution is discovered by way of asocial learning, or a combination of asocial and social learning, dictates its designation as innovation by invention or innovation by modification (point i). In Cutting, Apperly, Chappell and Beck (2014), children were shown a ready-made pipecleaner hook if they failed to solve the hook-making task (described in point i). This may be regarded as both innovation by invention (despite having social information in the form of a pre-made hook, the social information itself is not being directly modified; rather, children are still required to invent the means by which to create the hook) and goal emulation (the socially observed goal is reproduced via the individual’s own means).

The matter becomes more convoluted in the event that the goal being reproduced is one which does not solve the problem at hand, as ‘good’ innovations should work (Hauser, 2003). Behaviour that would otherwise be labelled ‘goal emulation’ crosses into the boundary of ‘innovation’ only when the novel modification of the pre-existing behaviour is useful and successful. When these criteria are not fulfilled, goal emulation indicates exploration and curiosity; an appreciation of alternative behavioural potentials when the cognitive capacity, motivation, or any factor reviewed above is not yet sufficient to enable the innovation process. In this way, goal emulation may be seen as a precursor to innovation in childhood (or a weak form of; see Whiten & Flynn, 2010, whose ‘innovate-minor’ category for children has the properties of emulation).

It is similarly pertinent to ask when the omission of actions within a behavioural sequence becomes an innovation, i.e., a new modification. Goal emulation can involve such omissions, as in Horner and Whiten's (2005) comparative study. Whereas 3- to 4-year-old children imitated both causally relevant and irrelevant actions in a tool-use task, irrespective of the availability of causal information (a transparent, but not opaque, puzzle box allowed the irrelevance of the actions to be seen), chimpanzees disregarded the irrelevant actions "in favor of a more efficient, emulative technique" (p.164) when the box was transparent. Thus, the chimpanzee behaviour became more efficient but the goal itself, retrieval of a food reward, was not altered. Though apes emulate to a higher degree than children, their lack of faithful transmission mechanisms means more efficient behaviours are rarely acquired by others, resulting in an absence of cumulative culture (Dean et al., 2013). In summary, emulation and innovation by modification are differentiated by a change in goal: with innovation the outcome of the behaviour must be better or more efficient (e.g., retrieval of more food), whereas with emulation the details of the behaviour involved in order to reach that outcome increase in efficiency (e.g., fewer steps in the behavioural sequence).

- vi. An innovation should be useful and/or transmitted.

Although controversial, we believe many innovations are likely to be beneficial and adaptive for the individual and the population in the event of their successful social transmission. This complies with the human literature wherein there is the implication that innovations should represent an improvement upon current behaviour (Caldwell & Millen, 2010) and allow us to formulate not only

solutions to problems but increasingly effective and efficient ones, enabling culture to evolve (Dean et al., 2013; Tennie et al., 2009). A caveat to the view of ‘useful’ innovations has emerged from studies of bird song, wherein innovations may be simply neutral in their fitness consequences as opposed to specifically adaptive or maladaptive (Slater & Lachlan, 2003). We can speculate that the same will be true of children’s innovations, particularly if they arise in the context of play. What children define as useful may be very different to what we adults define as useful; it may be enjoyable, for example, as opposed to serving a practical purpose. Open diffusion studies (see point iii), wherein deviation from established behaviour is seen (Flynn & Whiten, 2012), are well placed to infer what children regard as useful and, in turn, what is transmitted.

Maladaptive behaviour (inducing detrimental fitness consequences), however, also thrives within cultures. This may be because of indiscriminate copying, informational cascades, indirect transmission biases, copying errors and the transfer of outdated information (Rendell et al., 2011), as opposed to the spread of ‘bad’ innovations. The imitation of causally irrelevant actions and transmission of maladaptive information (by adults, Flynn & Smith, 2012; children, Horner & Whiten, 2005; guppies, Laland & Williams, 1998) demonstrates that a behaviour pattern may be functionally ineffectual and yet still succeed in spreading to other individuals. Is this to suggest that, regardless of outward utility, novel behavioural displays be considered innovations if they are reproduced by other individuals? The answer is probably yes. By their act of transmission, the implication is that they are of *some* use. The guppies in Laland and William’s (1998) study may take a longer and energetically more costly route to a feeder when a shorter route is available, but in doing so they are able to remain within the safety of the shoal. Therefore

‘usefulness’ of behaviour may not be immediately apparent, and additional motivations to learn ostensibly maladaptive information must be considered. Mechanisms such as ‘adaptive filtering’ (Enquist & Ghirlanda, 2007) provide a possible resolution to maladaptive cultural traits, contingent upon an individual’s capacity to perceive and correctly identify behavioural consequences and make innovative modifications accordingly.

- vii. An innovation need not reflect intentionality, but it should lead to learning.

Views surrounding the intentionality of an innovation feed into discussions of innovation sources and types (see point iv). Without the intention to act in a novel manner, we can assume subsequent production of innovative behaviour results from chance factors. We believe the inclusion of intentionality as an innovation criterion for children is unrealistic and unnecessary. Our argument is three-fold. First, the ability to plan behaviour develops gradually throughout childhood. This is especially true of the more cognitively complex and flexible *advance* planning, requiring one to anticipate action outcomes, in which children do not show higher levels of proficiency until aged 9-10 years or above (Tecwyn et al., 2014). This notion of forward projection of outcomes bears resemblance to intentionality. Complex planning is not, of course, a facet of all innovative behaviour, but it is a worthy consideration for more complex innovations nonetheless. Second, like insight, intentionality is difficult to determine. It is often indicated verbally when an intention is broken, but arguably less so when it is met. Third, whether arising from accidental occurrence or intentionality, novelty impacts upon an individual’s future behaviour (and, by extension, in cumulative culture) when it is learned and repeated,

both individually and more widely. We posit that an innovation technically remains an innovation but loses its value in the absence of its repetition and transmission.

For Ramsey et al. (2007) and Reader and Laland (2003), amongst others, an innovation can only be considered as such if it is accompanied by learning: if it becomes an established feature of behaviour, or if affordance learning is evident prior to the discovery of the innovative act itself. With regard to experimental tasks, we cannot be sure that children have demonstrated a novel *learned* behaviour in the absence of repeated trials with the same apparatus, nor is there opportunity to infer its origin or source: is it a purposeful behaviour executed with prior intentionality, the result of a trial-and-error approach or a one-off accident? It may also not be truly reflective of human culture to prescribe short time spans in which an innovation can occur. It should, however, be noted that learning is not universally considered to be essential to the innovation process, and a number of definitions do not require it. The matter of determining repetitions of innovative behaviour in the wild is a particularly tricky one, as animals are not observed continuously. Yet, whilst “trivial and idiosyncratic one-off” behaviour (Reader & Laland, 2003, p.11) is unlikely to be scientifically published (as an “interesting departure from established behavior”), actually observing an individual repeat a novel behaviour is *explicitly* suggestive of its effectiveness and significance. In addition to repetition, further measures of learning include iterative reductions in latency to solve a task using the innovation and verbal self-report. Ascribing intentionality to an innovation is therefore a minor issue compared to the more ultimate contribution that it may make to cultural evolution should it be learned.

2.4 Theoretical Contributions

2.4.1 Proposed Definition

The following operational definition is offered, drawing from the analysis undertaken in this review:

In the physical realm, a behavioural innovation is a new, useful and potentially transmitted learned behaviour, arising from asocial learning (innovation by independent invention) or a combination of asocial and social learning (innovation by modification), that is produced so as to successfully solve a novel problem or an existing problem in a novel manner.

We wish to note that, whilst verifying the occurrence of learning is the ideal, it is not at this stage essential. This criterion has the potential to inhibit research due to innovation's rarity in early to middle childhood (Beck et al., 2011). Attempts to assess learning, whether via behaviour repetition, task latency or verbal self-report, would nevertheless be both valuable and revealing, potentially uncovering age and individual differences in the extent to which it is evidenced by children.

2.4.2 Classifying Innovations

Rather than assigning innovation 'types' (Section 2.3.1, point iv), we propose a classification system based upon levels (see Table 2.1). The aim is to remove some of the focus from the *source* of the innovation, and allocate it instead to the *outcome*.

Learning, here, becomes the key component, and not whether the initial novel behaviour is accidental or insightful. In both instances, with learning, the outcome may well be the same. Should an innovation ultimately become a cultural trait, by way of its successful transmission and acquisition by others, we may regard it as of a higher level than an innovation that remains in the repertoire of only one individual. By thinking about innovations in terms of their larger cultural contribution and population-level consequences, we may achieve clearer discussion of their nature and avoid inconsistent use of terminology.

Table 2.1

Classifying Innovation

Levels	Criteria (whether Innovation by <i>Invention</i> or <i>Modification</i>)
1 : LOW	Unlearned ‘chance’ innovation not repeated by the individual
2 : MID	Individually learned innovation repeated by the individual
3 : HIGH	Individually learned innovation that is acquired by others
Types (from animal behaviour)	
Cognitively Simple/Complex (Whiten & van Schaik, 2007)	Simple: An innovation which could arise by individual discovery. Complex: An innovation which requires causal inference and deliberate action; not likely to arise by accident.
Weak Innovation/Invention (Ramsey et al., 2007)	Weak Innovation: An innovation in which social learning or environmental induction is implicated
Passive/Active (Rendell et al., 2007)	Invention: An innovation which is rarer, more novel, and involves more cognition. Passive: An innovation which is more likely to rely on chance events. Active: An innovation which is more likely to reflect cognitive abilities of the innovator.
Type I/Type II (Burkart et al., 2009)	Type I: An innovation which is goal-directed and problem-induced. Type II: An innovation which is more incidental.

Note. By presenting our ‘levels’ and earlier literature’s ‘types’, this table intends to highlight the increased clarity afforded by the former classification. Transition from mid to high level innovation does not necessarily directly link to the ‘usefulness’ of the innovation but may be a function of other social and contextual factors, such as the dependency of transmission on the identity of the innovator, due to directed social learning or transmission biases. Owing to its cultural transmission ramifications, learning is a key, and ideal, component of our levels criteria. However, it is not at this stage essential to demonstrate in child research given the difficulties of observing repetitions of innovative behavior.

2.5 Conclusion and Future Directions

The pivotal role of innovation in behavioural change and cultural evolution has prompted much research interest from a wide variety of disciplines, but thus far has been met with comparatively little attention from developmental psychologists. Its cognitive and cultural ramifications, and relevance to numerous contemporary contexts, including business enterprises, medical practices, education reforms, and climate change, underscores the imperative need to better understand the process and development of innovation. Throughout this article we have attempted to convey how emulating the advances of animal behavior research, and establishing a clear and consistent terminology, will be a crucial first step towards addressing this need and placing developmental psychology firmly on the stage of innovation research. In presenting a theoretical pathway to innovation and a new classification system, we also hope to stimulate interdisciplinary conversation and debate, encourage evidence-based conceptual frameworks, and prompt further experimental work.

Our provision of innovation criteria is intended to promote and support future research in this domain. We note, however, that whether a criteria consensus is gained or not, criteria of *any* sort will be of no value should researchers not be explicit in their own decisions regarding what will and will not be accepted as instances of the phenomenon, and take steps to create tasks, and task contexts, reflective of these aims. If, for example, we contend that innovations should represent better or more efficient ways of achieving goals, then an arbitrary alteration of a task solution (i.e., turning a manipulandi left versus right) reveals very little in this regard. Similarly, one task trial (that is, attempts with a novel task) discloses little about an innovation's origin and cannot verify the occurrence of learning. Examining task solution alternation, only possible with the implementation of a number of response trials (Wood et al., 2013), is a promising way of comprehending imitative or innovative strategy use over time and, through the manipulation of other variables of interest, what is viably responsible for conservatism and flexibility in children's learning. The implementation of multiple experimental trials, and multiple 'generations' of learners, will establish confidence in the findings of innovation (and innovation-related) research.

As we face a host of environmental, social and economic issues at a global level, taking steps to promote innovation will be key. Studies examining the ontogeny of tool innovation and the factors affecting age-related competence are needed to uncover consistencies in how and when this capacity emerges, as well as research examining consistencies in the innovative tendencies of individuals, populations (i.e., cross-cultural comparisons) and species. Such studies would allow for the identification of factors reliably implicated in observations of learning strategy variance, and their systematic promotion. An appreciation of how

competence interacts with motivational state, reward value, and social context will aid in the critical disentanglement of individual differences in innovative propensities. Without a better understanding of the innovation phenomenon we cannot hope to truly understand humanity's uniqueness, cultural complexity, and future ability to adapt – nor our capacity to nurture and cultivate it.

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Chapter 3

Imitate or innovate? Children's innovation is influenced by the efficacy of observed behaviour

Abstract

This study investigated the age at which children judge it futile to imitate unreliable information, in the form of a visibly ineffective demonstrated solution, and deviate to produce novel solutions ('innovations'). Children aged 4 to 9 years were presented with a novel puzzle box, the Multiple-Methods Box (MMB), which offered multiple innovation opportunities to extract a reward using different tools, access points and exits. 209 children were assigned to conditions in which eight social demonstrations of a reward retrieval method were provided; each condition differed incrementally in terms of the method's efficacy (0%, 25%, 75%, and 100% success at extracting the reward). An additional 47 children were assigned to a no-demonstration control condition. Innovative reward extractions from the MMB increased with decreasing efficacy of the demonstrated method. However, imitation remained a widely used strategy irrespective of the efficacy of the method being reproduced (90% of children produced at least one imitative attempt, and imitated on an average of 4.9 out of 8 attempt trials). Children were more likely to innovate in relation to the tool than exit, even though the latter would have been more effective. Overall, innovation was rare: only 12.4% of children innovated by discovering at least one novel reward exit. Children's prioritisation of social information is consistent with theories of cultural evolution indicating imitation is a prepotent response following observation of

behaviour, and that innovation is a rarity; so much so, that even maladaptive behaviour is copied.

3.1 Introduction

Social learning provides the foundation for culture. Acquiring information through observation is a rapid, cheap and largely efficient way to learn. Yet, on occasion, social information is outdated or inappropriate, especially in changing environments; thus its use must be modulated to support accurate and reliable information acquisition (Boyd & Richerson, 1985; Kameda & Nakanishi, 2002). Accordingly, personal sampling of the environment, even if costly, is a necessity (Laland, 2004). Theoretical models have suggested many learning heuristics (cultural transmission biases; Boyd & Richerson, 1985 and social learning strategies; Laland, 2004) which enable selectivity in social learning. These heuristics help direct whom, when and what we copy by inducing accuracy-cost evaluations of observed and personal information and, in turn, adaptive trade-offs in reliance on social and asocial (individual) learning (Kendal, Coolen, & Laland, 2009; Kendal, Coolen, van Bergen, & Laland, 2005).

Adaptive informational trade-offs have been shown in a variety of non-human animals (including species of fish, rats, monkeys and birds; see Galef & Laland, 2005; Kendal et al., 2009). By pitting social and personal information against one another, it appears that, “animals use social information primarily as plan B, or a backup when personal information is too costly to obtain, unreliable or outdated” (Rieucou & Giraldeau, 2011, p.950). In van Bergen, Coolen and Laland (2004), three groups of nine-spined stickleback fish were provided with personal information that varied in its level of reliability (56%, 78% or 100% reliable). This information related to the profitability of food patches within the experimental tank, and was determined by the number of trials in which ‘rich’ and ‘poor’ feeders could

be accessed. A social ('public') demonstration then provided conflicting information as to the location of the rich feeder. In spite of this demonstration, a significant number of sticklebacks within the 100% group (19 of 23) continued to visit the feeder they had personally experienced as rich, thus negating the conflicting social information. As with van Bergen et al. (2004), in the current study we manipulated information reliability with the aim of observing adaptive trade-offs in learning. However, given children's proclivity for imitation, and apparent tendency to collect social information despite possessing adequate personal information (Wood, Kendal, & Flynn, 2013a), we did so by manipulating the reliability of *social* information.

Children are exceptional imitators from a young age, reproducing behaviour with high levels of fidelity across contexts (Matheson, Moore, & Akhtar, 2013) and in the absence of causal knowledge of its relevancy (Lyons, Young, & Keil, 2007). Indeed, they are deemed 'cultural magnets' (Flynn, 2008) in their ability to both rapidly acquire and transmit information socially (Flynn & Whiten, 2008; Hopper, Flynn, Wood, & Whiten, 2010). However, children are not blind to the quality of information they observe. By altering the frequency and fidelity with which they imitate, in line with the perceived goal of a demonstration (Bekkering, Wohlschläger, & Gattis, 2000; Carpenter, Call, & Tomasello, 2005), model reliability and intentionality (Birch, Vauthier, & Bloom, 2008; Carpenter, Akhtar, & Tomasello, 1998), task difficulty and prior experience (Gardiner, Bjorklund, Greif, & Gray, 2012; Pinkham & Jaswal, 2011; Williamson & Meltzoff, 2011; Wood et al., 2013a), children display rationality and flexibility in their social learning (Koenig & Sabbagh, 2013; Mills, 2013; Over & Carpenter, 2012).

A variety of factors, including context, model characteristics and information content, affect the use of social information (Rendell et al., 2011; Wood, Kendal, &

Flynn, 2013b); here, our focus is on the efficacy of the information content. Action efficacy should arguably be a foremost determinant of what (and if) we choose to copy. By 3 years of age children distinguish correct from incorrect actions in their imitative behaviour, only reproducing those that have a desired causal effect (Want & Harris, 2001). Further, prior personal difficulty with a task does not induce 3-year-olds to have a copy-all approach when non-efficacious acts are demonstrated (Williamson, Meltzoff, & Markman, 2008). If a causal relationship is unknown, faithful imitation may result. However, if action sequences are repeatedly poor at producing desired outcomes, their efficacy should be questioned and imitation less likely to occur. Thus, logically, in circumstances under which a sequence of behaviour is never or rarely effective at achieving a goal, individuals should try new methods.

Few studies have attempted to examine how evaluations of efficacy affect selective imitation, and subsequent novel action production (or *innovation*). Schulz, Hoopell and Jenkins (2008) tested 18-month-olds and 4-year-olds in conditions that differed in an action's efficacy: deterministic, in which the actions activated the toy on all trials and stochastic, in which actions activated the toy on 50% of trials. Children of both age groups imitated with significantly lower fidelity in the stochastic condition than the deterministic condition, irrespective of whether the action satisfied the explicitly stated goal of the model. Thus, in the stochastic condition, efficacy overrides pedagogy. However, as Schulz et al. (2008) acknowledge, the potential for alternative responses on the task, and the opportunity to observe behavioural innovation, was limited.

In recent years, interest in childhood innovation has grown, and studies suggest that, in the tool-use domain, innovation is a relatively late-developing

capacity (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; Hanus, Mendes, Tennie, & Call, 2011; Nielsen, 2013) and a rare response for children (Whiten & Flynn, 2010). Factors such as functional fixedness (German & Defeyter, 2000), explicit instruction (Bonawitz et al., 2011), prior social information (Wood et al., 2013a), and task structure (Cutting, Apperly, Chappell, & Beck, 2014) likely constrain it. Innovation can be delineated in terms of arising from asocial learning (innovation by independent invention) or a combination of asocial and social learning (innovation by modification: Carr, Kendal, & Flynn, accepted: Chapter 2). Most research investigating children's innovation has examined novel tool invention as opposed to novel modification. Yet, examination of the latter is critical as it is of great importance for *cumulative* culture (Lewis & Laland, 2012), where, over generations, humans build upon and improve pre-existing knowledge (Dean, Kendal, Schapiro, Thierry, & Laland, 2012). Currently we do not know whether innovation by modification has the same late developmental trajectory as independent invention. The current study addresses this issue through the provision of social demonstrations to individual children, across the age range of 4 to 9 years, followed by multiple response trials, thus providing many opportunities for innovation as well as multiple tools with which to innovate.

We ask, when evaluating efficacy of observed actions, at which point do children judge it futile to imitate? Do we see different assessments of redundancy at different ages? And does varying action efficacy make children more likely to innovate (produce novel behaviour) when given sufficient opportunity and means to do so? Even if children do not know of a behavioural alternative, they should nevertheless explore novel actions (Schulz et al., 2008) - trading-off social information for potentially more reliable personal information.

Our study used a novel artificial fruit (Whiten, Custance, Gomez, Teixidor, & Bard, 1996), the Multiple-Methods Box (MMB), a puzzle-box offering scope for exploration and innovation (we distinguish exploration and innovation here as they are regarded as qualitatively distinct (Reader & Laland, 2003): you may explore, but you may not always innovate). Drawing from van Bergen et al. (2004), children were provided with social demonstrations that differed in solution efficacy: the proportion of trials (0, 25, 75, 100%) that a reward could be extracted from the exit door of the MMB. Multiple demonstration and attempt trials were provided to reduce the likelihood that the novel task and experimental context would incite a copy-when-uncertain bias (Laland, 2004) and to monitor if, and how, participants changed their reliance on social and/or personal information over trials (Flynn & Smith, 2012; Wood et al., 2013a). With increasing experience with the MMB, both through observation and personal use, participants could establish the demonstrated method's efficacy and, in the lower efficacy conditions, appreciate the redundancy of repeating a method that simply did not work.

Children aged 4 to 9 years were selected so as to capture developmental change and is in keeping with that of previous innovation research (Beck et al., 2011). Moreover, children are adept at assessing efficacy by 4 years (Want & Harris, 2001; Williamson et al., 2008) and able to differentiate information that is reliable 75% of the time from information that is reliable 25% of the time (Pasquini, Corriveau, Koenig, & Harris, 2007). We predicted, in line with Want and Harris (2001) and Schulz et al. (2008), that lower levels of solution efficacy would be associated with reduced imitation (lowered fidelity to the socially demonstrated method), and, further, increased innovation (specifically, innovations that altered the reward exit and thus allowed for extraction). Moreover, we anticipated that older

children would be better equipped to both evaluate levels of solution efficacy (resulting in a stronger negative relationship between efficacy and innovation with increasing age) and reach effective innovative solutions (with the greatest rates of successful innovation being seen in the oldest age group). In turn, we predicted that, overall, the oldest children would be the least faithful to the socially demonstrated method. Finally, given the range of novel behaviours that could be produced with the MMB, we explore how participants deviated from the socially demonstrated method (if and when they did) with regard to whether they changed the tool, access point or, most effectively, the exit. We assessed the children's performance against the performance of adults, whom we predicted should innovate, particularly in the lowest efficacy condition.

3.2 Method

3.2.1 Participants

Two hundred and fifty-six children (128 males) from three primary schools in the North East of England participated. Three age groups were created: 4-5 years ($N = 73$, $M = 5$ years 4 months (5;4), range 4;8-5;11), 6-7 years ($N = 96$, $M = 7;0$, range 6;0-7;10), and 8-9 years ($N = 87$, $M = 8;10$, range 8;0-9;9). Forty-five Durham University students also participated (23 male, $M = 20$ years 7 months (20;7), range 18;6-27;7).

3.2.2 Materials

A novel puzzle box task, the ‘Multiple-Methods Box’ (MMB; see Figure 3.1), was used. The MMB contains two levels separated by an opaque platform. The upper transparent level featured: an entry chute for a reward (a capsule containing a sticker which was inserted by the experimenter); four entrances, one of which required the rotation of a dial for access and three of which could also function as reward extraction points; and a small circular hole in the platform floor. If the capsule was manipulated to fall through this hole (as in the social demonstrations) it dropped to a lower opaque level of the MMB via a concealed slope to rest behind a blue exit door. A small independent remote control device was used to discretely lock and unlock the exit door in line with predetermined levels of solution efficacy. When unlocked the door could be lifted to acquire the capsule from behind.

Three tools were available: a fork, a hook and a sweep tool (Figure 3.1b). The varying dimensions of both the MMB and the tools introduced an additional problem solving component to the task by limiting random application of the tools; that is, not all tools fitted into all access points or were long enough to manipulate the capsule to all exit holes. Further, the fork and sweep tool could be joined and used in combination to extract the reward across a longer distance than the other single tools. The social demonstration involved inserting the fork tool into the smaller inverted T-shaped entrance (labelled 1 in Figure 3.1), the reward was caught in the ‘U’ of the fork and manoeuvred so that it fell through the hole in the platform floor.

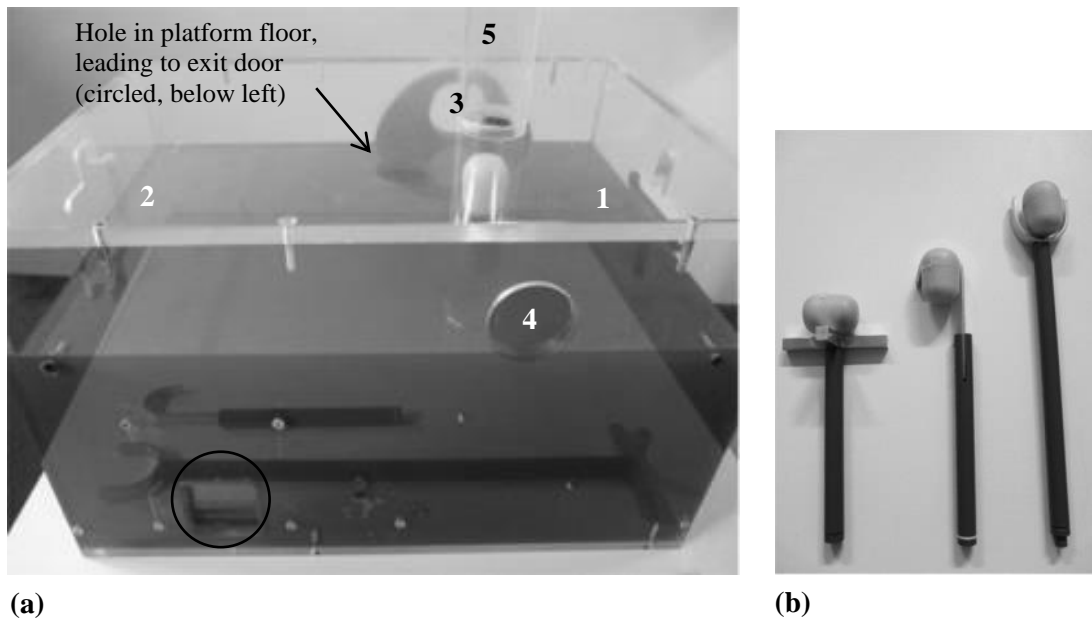


Figure 3.1. The Multiple-Methods Box (MMB) and associated tools. (a) Access points labelled 1-5: (1) ‘Social’, small inverted T-shape, used in social demonstrations, (2) ‘End’, large inverted T-shape, opposite ‘Social’, (3) ‘Dial’, circular hole, revealed by aligning the circle of a dial with a circle in the side of the box, (4) ‘Dial Opposite’, and (5) ‘Entry Chute’, a circular hole into which the reward was dropped. (b) Three tools were available, from right to left: fork, hook and sweep. The position of the capsule in relation to each tool demonstrates the main method of manoeuvre. The fork and sweep tool could be joined and used in combination to extract the reward, with the extra length affording extraction across the full length of the MMB, and can be seen in the reflection at the base of the box (a).

3.2.3 Design

Children from each age group were randomly allocated to one of four social experimental conditions, differing incrementally in the efficacy of the demonstrated method of reward extraction. The method itself was consistent across all

demonstrations and conditions. Method efficacy was operationalised as the number of demonstration trials, out of eight, in which the capsule could be removed from the exit door. The method was efficacious on either 0 of 8 trials (0% condition, $N = 60$), 2 of 8 trials (25% condition, $N = 48$), 6 of 8 trials (75% condition, $N = 50$) or 8 of 8 trials (100% condition, $N = 51$). Importantly, the level of method efficacy observed during the experimenter's demonstrations was mirrored in participants' own subsequent attempts with the task, such that their personal experience with the MMB matched their observational experience (if they chose to reproduce the demonstrated behaviour). A further 47 children were assigned to a no-demonstration control condition in which they witnessed no social demonstrations (see Table 3.1 for the distribution of participants across groups). This condition provided a baseline measure of performance on the task, specifically the level of performance of the actions presented within the social demonstration and the level of new method generation without prior method demonstration. The adult participants were allocated to either the 0% or 75% efficacy condition as it was here that major differences were seen in the child sample.

Table 3.1

Distribution of Participants Across the Experimental Conditions and Age Groups

	Baseline	0%	25%	75%	100%	Total
4-5 yrs	14(8)	17(9)	14(7)	15(9)	13(8)	73(41)
6-7 yrs	18(9)	20(11)	18(10)	19(9)	21(11)	96(50)
8-9 yrs	15(8)	23(10)	16(7)	16(6)	17(6)	87(37)
Total	47(25)	60(30)	48(24)	50(24)	51(25)	256(128)

Note. Number of males given in parentheses.

3.2.4 Procedure

Children were tested individually in a quiet area of their school. First, they were familiarised with the MMB during a short warm-up phase. To attempt to reduce assumed experimenter expertise and potential model-based biases (Wood, Kendal, & Flynn, 2012), the box was proclaimed as belonging to a friend, “This is actually my friend’s box, and my friend told me that when this egg [the capsule] goes into the box you have to try and get it out. Inside this egg is a sticker. If you get it out of the box, we can start a sticker pile for you and we’ll see how many you can get”. Anecdotally, many children appeared to accept this premise by enquiring into the name of the friend. The tools were presented alongside the box: “Can you see these tools here? My friend also told me that some of these tools can be joined together”.

Children in the no-demonstration control condition received a prompt to begin interacting with the MMB immediately following this familiarisation: “You can have some turns at seeing if you can get the egg out of the box. You can do anything you like.” The exit door was unlocked throughout for control participants. Children in the social conditions were informed: “I’m going to have eight turns at trying to get the egg out of the box. Let’s see if it works”. The experimenter proceeded to demonstrate the same method of reward retrieval (fork tool through ‘Social’ access point, capsule to exit door via hole in floor) eight times with only the outcome differing between the four experimental groups. Neutral comments, “I got it out of the box/I didn’t get it out of the box”, were made after each demonstration. As the concealed exit chute connecting the circular hole in the upper platform floor and the lower exit door was capable of holding eight capsules, it was not necessary to remove ‘locked’ capsules in between experimenter demonstrations. However, for

those conditions in which locked capsules had to be removed prior to participants' attempts (0-75% conditions), children were distracted with a non-cognitively demanding task (organising sheets of stickers) for the very short time (<10 seconds) it took to remove these capsules.

Participants were given a maximum of eight attempt trials, over a period of five minutes (if the eight trials were not completed within this time, which was rare, testing ceased). Participants who had received social demonstrations were told, "Now it's your turn to see if you can get the egg out of the box. You can do anything you like". Each trial constituted one participant's attempt, for which strict criteria were applied. An attempt was defined as the insertion of a tool into the box with the purposeful intention, or realisation, of making contact with the capsule prior to the tool's extraction. 'Purposeful' denotes engagement with the task as indicated by head and gaze orientation and 'intention' evidenced when a tool was fully inserted but too short to reach the capsule. An attempt was complete when a tool was fully extracted (even if then replaced into the same access point). Some innovative methods of reward retrieval involved performing more than one action – for example, pushing the capsule with the fork tool towards the 'End' of the MMB before using the hook tool to extract it. In the event that a child displayed continued purposeful intentionality and interaction with the MMB, therefore, this was considered part of the same attempt. The apparatus was re-baited upon commencing each trial, unless full contact with the capsule was not previously made or the capsule was moved only a very small distance. The removal of the lid of the box, concealed by a large fabric sheet, allowed capsules to be quickly retrieved in the event of their unsuccessful extraction. As with demonstrations, neutral comments were made following each attempt trial ("You got it out of the box/You didn't get it out of the box").

For comparability, and to control for primacy and recency effects, the demonstration sequence of the two conditions involving uncertainty (25% and 75%) began and ended with a success (S, door unlocked) followed by an unsuccess (U, door locked). The full demonstration sequence for the 25% condition was thus: S, U, U, U, U, S, U, and for the 75% condition: S, U, S, S, S, S, S, U. The same sequences were implemented for participants' subsequent attempts with the MMB. In this attempts phase, the experimenter ensured only one capsule was extracted on those occasions in which the exit door was unlocked and additional capsules had accumulated in the exit chute. Whilst recognising that it would not always be feasible to fully mirror the efficacy of demonstrated social information in participants' attempts, given that different numbers of the socially demonstrated method could be attempted prior to the enactment of alternative methods, at the very least participants were given some experience of efficacy variability in their first two trials (i.e., success followed by unsuccess) for these two conditions. It should be noted that enactment of alternative methods that utilised the exit door (alternative by way of a novel tool and/or access point) resulted in the same experience of efficacy as that of the socially demonstrated method.

At the end of testing all children were praised for their performance and rewarded with a sticker irrespective of their level of success (small stickers collected during testing were traded for one larger and more desirable sticker). The above protocol was followed for adult participants in a University laboratory, within either the 0% or 75% conditions. They received departmental credits for their participation or a £5 Amazon voucher, irrespective of their performance.

3.2.5 Coding and Inter-Rater Reliability

The performance of each participant was scored for a number of variables in each response trial: (a) tool selected, (b) access point used, (c) exit location (if any), (d) outcome (no outcome, capsule to exit door but no extraction, and extraction), and (e) learning strategy. Full rationales for the different strategies are presented in the Results section but, in short, the strategy was determined by the aforementioned (a)-(c), such that:

- Imitation = same tool, same access point, and same exit as used in social demonstrations
- Tool/access point innovation = different tool and/or access point, but same exit as used in social demonstrations¹
- Exit innovation = different or same tool/access point, and different exit as used in social demonstrations (unlike alterations to the tool or access point, discovering a new exit has the potential to change the outcome of the task)
- Unsuccessful action = abandoned attempt prior to removal of capsule or it reaching the exit door.

From these individual response trial variables, several additional variables were created to capture overall task behaviour (Table 3.2). The experimenter, KC, coded 100% of the sample from video tape. An independent observer, blind to the hypotheses of the study, coded 20% of the sample. All Cohen's Kappa scores and correlation values were 0.85 or above, showing an excellent level of inter-rater reliability.

¹ This is in essence 'end-state emulation' (Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009). However, as the end state was manipulated to produce method efficacy, it was not possible to investigate the development of end-state emulation in and of itself.

Table 3.2

Attempt Trial Variables Subject to Statistical Analysis

Variable	Description
Copying Fidelity	Score of 1-4 was given for each trial: 1 for no new components (tool/access/exit), 2 for one new component, 3 for two new components, and 4 for three new components. These were summed across the eight attempt trials (max. 32).
Tool/Access/Exit Innovations	Total number of novel (to the child) tools/access points/exits used across attempt trials.
Imitation Attempts	Total number of attempts in line with strict imitation definition (same tool, access and exit; max. 8).
Tool/Access Innovation Attempts	Total number of attempts in line with tool/access point innovation definition (new tool and/or access, but same exit; max. 8).
Exit Innovation Attempts	Total number of attempts in line with exit innovation definition (same or different tool and/or access, and different exit; max. 8).
Alternative Methods	Total number of different methods (new combinations of tool, access and exit) enacted, excluding socially demonstrated method and irrespective of success (max. 8).
Extractions	Total number of successful capsule extractions, irrespective of extraction method (max. 8).

Note. Attempts at retrieving the capsule were deemed more revealing than successful extractions, as, according to the experimental design of the study, on some trials the capsule reached the exit door but it was locked and so could not be extracted. Here, participants' persistence with an unsuccessful method was evident.

3.2.6 Statistical Methods

As the data were not normally distributed, non-parametric tests were used. Although we were selective with follow-up tests (Mann-Whitney and Wilcoxon rank-sum), to avoid inflating the Type I error rate a Bonferroni correction was applied by dividing the critical significance level of .05 by the total number of tests conducted. Probability values reported with an asterisk indicate the significance level required to reject the null hypothesis following this correction.

3.3 Results

The results are presented in four sections. First, we explore how control participant's success and method use compared to that of 100% efficacy social demonstration participants. The 100% condition is the most valid comparison as the door remained unlocked for all trials, as it did in the no-demonstration control condition. The second section considers copying fidelity, broadly defined and then in relation to typical definitions of imitation, followed in the third section by a consideration of deviations from demonstrated behaviour. Finally, innovation, along with its various manifestations, and its role in low efficacy social conditions is investigated. As the sex of participants was not found to significantly affect our

outcome measures, it was excluded from all reported analyses. All tests are two-tailed unless otherwise stated.

3.3.1 What Were the Level of Success and Methods Used by Children in the No-Demonstration Condition?

Of the 47 controls, nine (19.2%, six males, four 4-5 years and five 6-7 years) failed to produce one attempt; instead, they touched and explored the MMB with their hands but never made contact with the capsule (despite having the tools introduced at the beginning of their turn). In comparison, all 209 children from the social conditions attempted the task (whether successful or unsuccessful in terms of extraction). 36 of the 47 controls succeeded in making at least one capsule extraction. However, control participants achieved significantly fewer extractions ($Mdn = 5$, $SD = 2.56$) than those in the 100% condition across the attempt trials ($Mdn = 7$, $SD = 2.09$; Mann-Whitney $U = 588.50$, $z = -4.42$, $p < .001$).

The main point of concern which the control condition allowed us to address was whether the socially demonstrated method was a naturally salient response to the task. Of the 38 control participants who produced at least one attempt, only two produced the method of social demonstrations on more attempt trials than any other method. Controls ($Mdn = 0$, $SD = 0.81$) also performed the method of social demonstrations on significantly fewer attempt trials than participants in the 100% condition ($Mdn = 6$, $SD = 2.63$; $U = 131.00$, $z = -8.01$, $p < .001$), whilst attempting a significantly *greater* number of alternative methods (control: $Mdn = 2.5$, $SD = 1.61$; 100%: $Mdn = 1$, $SD = 1.08$; $U = 361.00$, $z = -5.17$, $p < .001$). Control participants produced a median of 2.5 alternative methods, thus they did not simply discover one

means of solving the task and adhere to it. Nevertheless, the majority of children repeated successful methods ($N = 30$, $Mdn = 2$, $SD = 2.42$). Within the control group, the 8- to 9-year-olds produced a greater median number of successful alternative methods ($Mdn = 3$, $SD = 1.55$) than 6- to 7-year-olds ($Mdn = 2$, $SD = 1.61$) and 4- to 5-year-olds ($Mdn = 1$, $SD = 1.70$).

Whilst any successful method discovered in the no-demonstration control condition would technically constitute an innovation, because it is a different kind of innovation to that required in the social conditions (invention versus modification) it is not possible to compare them like-for-like. Hence, the focus above is on alternative methods.

3.3.2 Did Children Imitate the Socially Demonstrated Method?

Children received a score according to the number of new components each attempt contained (explained in Table 3.2). A score of 1 indicated faithful reproduction of the socially demonstrated method, whilst 4 indicated complete deviation from this method. The attempts that had no outcome (they were abandoned, by extracting the tool from the box before an outcome was produced) could receive a maximum score of 3 only due to the unknown exit. A total of 122 participants (58%) produced at least one such abandoned attempt and they accounted for 15.6% of all attempts. The following analyses were run with the abandoned attempts (unsuccessful actions) both included and excluded, with the same effects found. We report the former.

Analysis of total scores, summed across the eight attempt trials, revealed no significant differences between efficacy conditions (Kruskal-Wallis $H(3) = 2.82$, $p =$

.42). Children's mean scores in all conditions ranged from 11 to 12.5 (for adults, the overall mean score was larger at 17.42; range of 22). Given that the minimum possible score was 8, denoting complete fidelity throughout attempts, and the maximum 32, children showed little (though some) deviation from demonstrated behaviour, irrespective of condition. Age differences were found in copying fidelity ($H(2) = 12.32, p = .002$). Specifically, 4- to 5-year-olds showed significantly higher copying fidelity ($Mdn = 9, SD = 3.98$) than 6- to 7-year-olds ($Mdn = 11, SD = 4.02, U = 1732.5, z = -2.53, p = .01$) and 8- to 9-year-olds ($Mdn = 11.5, SD = 4.32, U = 1397, z = -3.43, p = .001$).

Definitions of imitation usually require that both the goal, and the specific actions used to achieve it, are recognised and reproduced (Tomasello, 1990). Such 'pure' imitation, involving use of the fork tool, through the 'social' access point, and extraction (or *attempted* extraction) from the exit door, was the dominant strategy used on the MMB task. This was seen in participants' first attempt trial (68% of which met the criteria for 'pure' imitation) and overall (most common strategy across attempt trials for 67% of children). As the exit door was unlocked for all participants on the first trial, excepting those in the 0% condition for whom it was always locked, the first enactment of the socially demonstrated method allowed for successful extraction.

In spite of the dominance of this imitation response, it was mediated by age ($H(2) = 8.86, p = .012$). The number of imitation attempts was significantly higher for the youngest age group (4-5 years, $N = 59$) when compared with 6- to 7-year-olds (Mann Whitney, $N = 78, U = 1758.50, z = -2.41, p = .016$) and 8- to 9-year-olds ($N = 72, U = 1518.00, z = -2.85, p = .004$; see Figure 3.2). The latter two groups did not significantly differ ($U = 2752.50, z = -0.21, p = .83$), nor did the experimental

conditions ($H(3) = 2.54, p = .47$). However, an effect of condition was found for adults, who produced significantly more imitation attempts in the highest (75%) efficacy condition ($Mdn = 4, SD = 2.88$) compared with the 0% efficacy condition ($Mdn = 0, SD = 0.65$): $U = 41.50, z = -5.01, p < .001$).

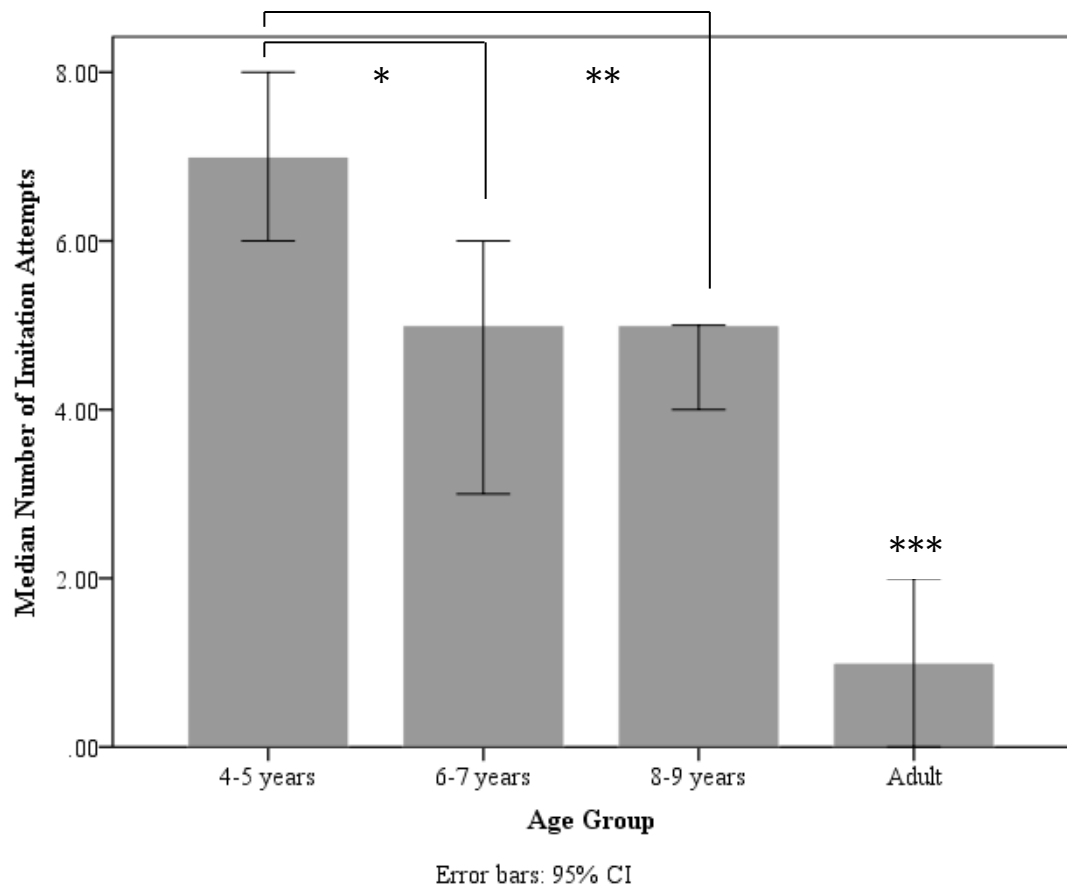


Figure 3.2. Median number of ‘pure’ imitation attempts by age group. The asterisks above the adult bar denote that these participants were significantly different to all other age groups. $*p < .05$, $**p < .005$, $***p < .001$

3.3.3 How did the Children's Behaviour Deviate From the Demonstrated Behaviour?

To establish which component of the method (tool, access, exit) was most likely to be modified, separate scores were created for the number of novel tools (maximum 5; hook, sweep, combined fork, combined sweep, tool end), novel access points (maximum 4; end, dial, dial opposite, entry chute) and novel exits (maximum 3; end, dial, dial opposite) used across the attempt trials ('novel' denoting 'not seen' in demonstrations, and excluding repetitions).

A significant difference was found in method component modification or the 'type' of innovation (Friedman's ANOVA $\chi^2(2) = 114.94$, $p < .001$). Specifically, participants used significantly more novel tools throughout their attempt trials ($Mdn = 1$, $SD = 0.97$) than access points ($Mdn = 0$, $SD = 0.93$; Wilcoxon signed-ranks $z = -6.35$, $p < .001$) or exits ($Mdn = 0$, $SD = 0.61$; $z = -9.21$, $p < .001$). Participants also used significantly more novel access points than novel exits ($z = -5.96$, $p < .001$). These findings are further reflected in the total number of children (out of 209) who produced at least one of the different innovation types: tool innovation ($N = 132$), access innovation ($N = 86$) and exit innovation ($N = 26$).

In contrast, adult participants ($\chi^2(2) = 13.34$, $p = .001$) used significantly more novel exits ($Mdn = 2$, $SD = 1.14$) than novel tools ($Mdn = 2$, $SD = 0.85$; $z = -2.75$, $p = .006$). There was no significant difference in the use of novel tools and novel access points ($z = -0.18$, $p = .86$), and the difference between novel exits and novel access points neared significance ($Mdn = 1$, $SD = 1.18$; $z = -2.22$, $p = .027$, $p^* = .016$). Examining age differences in children's novel exit use, the oldest children ($Mdn = 1$, $SD = 0.86$) were the most proficient (6-7 years: $Mdn = 1$, $SD = 0.47$; 4-5

years: $Mdn = 1$, $SD = 0.28$), although the effect is only nearing significance ($H(2) = 5.79$, $p = .055$).

3.3.4 Improving Behaviour Efficacy: The Importance of Exit Innovation

The experimental task was designed such that exit innovations were the only way in which behaviour could be made more efficacious. Whilst modifications of the tool and access point are innovative departures from demonstrated behaviour, without modification of the exit they are of no more ‘use’ than the modelled method. Innovations should solve the problem at hand (Carr et al., accepted). Unlike the exit door, the top access points of the box are always open and thus can guarantee extraction success when used as exits. It is for this reason that only rates of exit innovation were included in the following analyses, and not rates of tool or access innovation.

Of the 209 child participants within the four social experimental conditions, only 26 individuals (12.4%) produced at least one exit innovation (age group differences are reported at the end of this section). Thus, whilst 10% of children never *imitated*, 87.6% of children never *innovated*. This is in contrast to the 33 of 45 adult participants (73.3%) who did produce at least one exit innovation. The disparity between ‘pure’ imitation and exit innovation as adopted task strategies, across ages, can be seen in Figure 3.3. Correlational analyses, using actual ages and mean number of attempts, indicated a significant negative correlation between imitation and age ($r_s(254) = -0.35$, $p < .001$) and a significant positive correlation between exit innovation and age ($r_s(254) = 0.47$, $p < .001$).

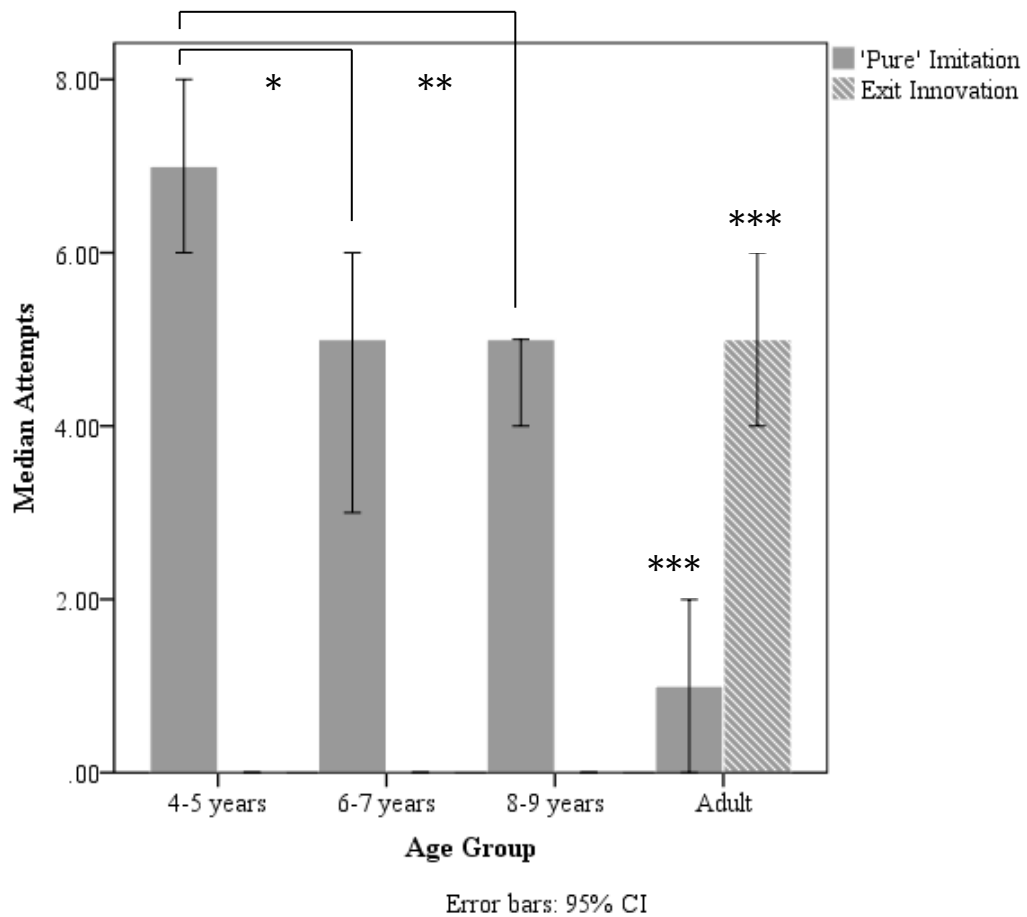


Figure 3.3. Median number of ‘pure’ imitation and exit innovation attempts by age group. The asterisks above the adult bar denote that these participants were significantly different to all other age groups. $*p < .05$, $**p < .005$, $***p < .001$

Children’s exit innovations typically appeared around the fourth attempt trial out of eight (see Table 3.3), suggesting that innovative problem solving was a cumulative process, with each trial or interaction with the MMB revealing more about its affordances, or that participants opted to explore once they had gained personal experience of the demonstrated method’s efficacy. A clear trend of increasing exit innovation with decreasing efficacy of the demonstrated method was seen. While 23% of children in the 0% condition (where the exit door never yielded to allow extraction) produced at least one exit innovation, this was true of only 13%

of children in the 25% condition and 6% of children in the 75% and 100% conditions.

Each innovation of the 26 individuals was ‘graded’ according to its complexity, thereby taking into consideration the tool and access point that accompanied the new exit. Scores were as follows: (1) new exit only, (2) new exit and new tool or access point, (3) new exit, new tool and new access point. In addition to grades, innovations were also categorised by their level. Higher-level innovations were determined by their repetition (and presumed learned status), deemed to be of cultural significance given the increased likelihood of their successful transmission and acquisition by others (as opposed to an innovation that is accidental or remains in the repertoire of only one individual: see Carr et al., accepted). A low-level innovation is defined as an ‘unlearned chance innovation not repeated by the individual’, to be contrasted with a mid-level ‘individually learned innovation repeated by the individual’ (the high-level category, ‘individually learned innovation that is acquired by others’, does not apply as this study did not allow for transmission of innovations to other individuals). The occurrence and number of repetitions, used to determine the level of the innovation, can be seen in the right-hand column of Table 3.3.

Table 3.3

Exit Innovations: Participant and Innovation Characteristics

Participant Characteristics			First Exit	No. of	Grade	Repetitions
Age	Sex	Condition	Innovation	New Exit		of Exit
(Years)			Trial	Innovations		Innovations
4-5	F	0%	1	1	1	4
	M	0%	8	1	1	0
	M	0%	2	1	3	0
	M	25%	6	1	1	0
	M	25%	5	1	3,1	1
6-7	F	75%	2	1	2	0
	M	0%	2	3	2,3,2,3	1
	M	0%	3	1	3	0
	M	0%	1	2	3,2	2
	M	0%	2	1	1	0
	M	25%	6	1	2	0
	M	25%	5	1	1	2
8-9	F	0%	3	2	1,2	0
	F	0%	3	2	1	1
	F	0%	8	1	1	0
	F	0%	4	1	1	2
	F	25%	4	2	1	1
	F	25%	7	1	2	0
	F	75%	3	3	3	0
	F	100%	6	1	2	0
	F	100%	4	1	1	2
	M	0%	1	2	3	2
	M	0%	4	3	3,2,3	0
	M	0%	2	3	1,2,3,1	2
	M	75%	5	2	2,1	0
	M	100%	2	3	3,3,2	1

Note. ‘Grade’ reflects the complexity (3 = most complex) of the novel behaviour as a whole (tool, access and exit), and are written in the order in which they were displayed. ‘Repetitions of exit innovations’ is a count of the number of times a newly discovered exit (i.e., not the exit door) was used again. It does not denote how many *different* exit innovations were repeated. The ‘new’ in ‘Number of new exit innovations’ relates to the child, and excludes the exit door used in social demonstrations. It does not denote how *many* capsules were extracted, only how many of the access points were discovered as exits.

There were no significant differences in the number of exit innovation extractions by age group ($H(2) = 5.39, p = .07$). However, as Table 3.3 indicates, there were age differences when considering exit innovations more closely. Of the five exit innovators in the 4-5 age group, no one individual discovered more than one novel exit. The number of individuals doing so increased in the 6-7 group ($M = 1.43$), and again in the oldest group ($M = 2.00$). Moreover, although overall there were very few repetitions of exit innovations ($M = 0.81$), adult participants displayed a higher mean number of exit innovation repetitions ($M = 3.21$) than children ($M = 0.81$), including those of the eldest children ($M = 0.79$), thus evidencing more innovations of mid-level status. A variety of ‘grades’ of innovation complexity were seen within each age group, and, while the innovations of some participants increased in complexity (progressing from a lower to higher grade during attempt trials), this trend was reversed for others.

Examining the number of exit innovations more widely across the four experimental groups (children only; Figure 3.4), a significant effect of condition was found (Kruskal-Wallis $H(3) = 10.82, p = .01$). As it was predicted that those

participants in the lowest efficacy conditions would innovate more than those in the higher efficacy conditions, a number of follow-up analyses were conducted. The results of these supported our predictions: participants in the 0% efficacy condition ($N = 60$, $Mdn = 0$, $SD = 1.40$) attained a significantly greater number of innovative extractions than participants in the 75% ($N = 50$, $Mdn = 0$, $SD = 0.52$; Mann Whitney $U = 1234.00$, $z = -2.54$, $p = .01$) and 100% conditions ($N = 51$, $Mdn = 0$, $SD = 0.70$; $U = 1261.50$, $z = -2.54$, $p = .01$), but not 25% ($N = 48$, $Mdn = 0$, $SD = 0.69$; $U = 1269.00$, $z = -1.56$, $p = .12$). The 25% condition did not significantly differ from the two higher efficacy conditions.

Of the 33 adults who produced one or more exit innovations, 23 belonged to the 0% efficacy condition and 10 to the 75% efficacy condition. Complementing the effect of condition found for children, adult participants in the 0% condition ($Mdn = 6.5$, $SD = 1.83$) attained a significantly greater number of innovative extractions than those in the 75% condition ($Mdn = 0$, $SD = 2.62$): $U = 63.00$, $z = -4.38$, $p < .001$.

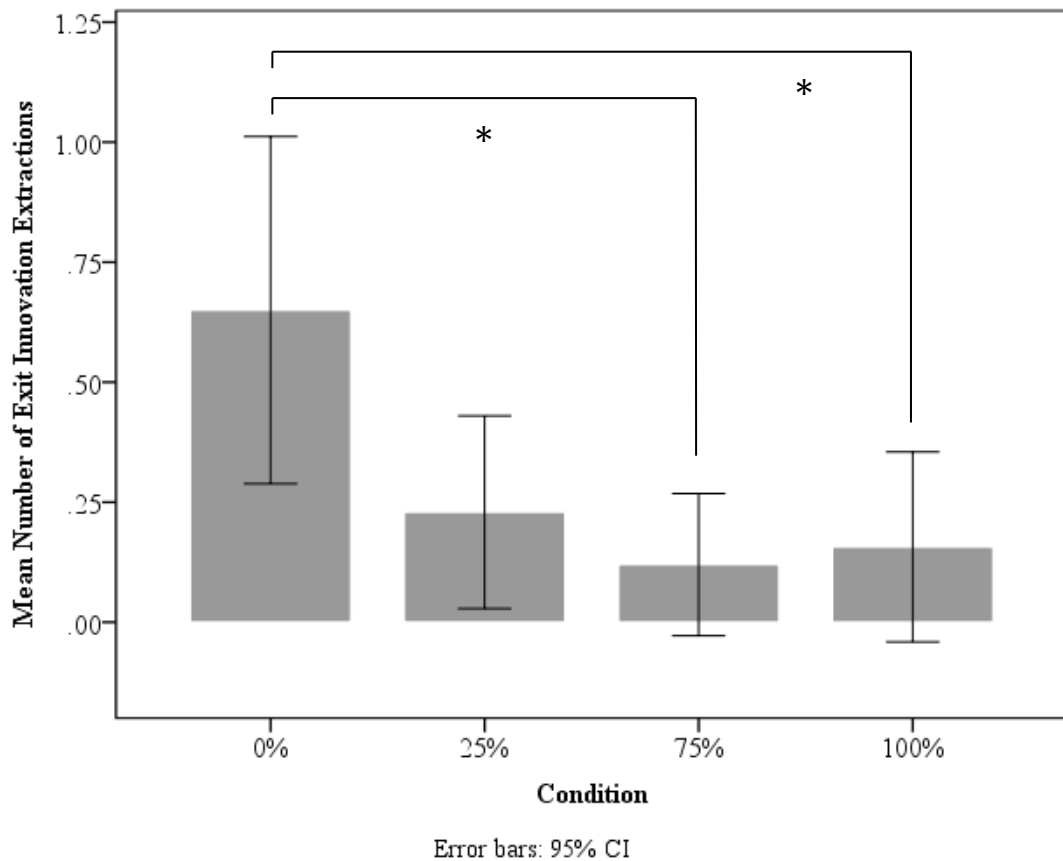


Figure 3.4. Mean number of exit innovation extractions across child experimental groups. Although non-parametric statistics were conducted, the means are displayed here given that the median score for each group was 0. $*p < .05$

In addition to group differences in the *performance* of exit innovations (including their repetition), we find differences in the *production* of exit innovations (new exit innovations only). Considering only new (to the child) exit innovations, the effect of condition was again significant (Kruskal-Wallis $H(3) = 10.63$, $p = .01$). Participants in the 0% condition produced significantly more new exit innovations across their eight attempt trials ($Mdn = 0$, $SD = 0.85$) than 75% ($Mdn = 0$, $SD = 0.52$; $U = 1243.00$, $z = -2.45$, $p = .014$) and 100% participants ($Mdn = 0$, $SD = 0.46$; $U = 1260.5$, $z = -2.54$, $p = .011$). The effect of age was nearing significance ($H(2) = 5.79$,

$p = .055$) with the older age groups producing more exit innovations than the youngest group (as also suggested by Table 3.3).

3.4 Discussion

Here we addressed the question of how children of different ages trade-off social versus asocial learning based on the efficacy of an observed solution. We also considered how innovation, through modification in tool use, develops. Lower levels of observed solution efficacy were associated with increased (exit) innovation in children, with older children being more likely to innovate than younger children. Between 6-7 years and adulthood, imitation of the socially demonstrated method decreased and innovation increased. Contrary to expectation, reduced imitation in response to lower levels of solution efficacy was not found for children. It was, however, seen in adults.

3.4.1 Fidelity to, and Deviations From, the Socially Demonstrated Method

Children reproduced modelled behaviour with high levels of fidelity across the different efficacy conditions, supporting previous research indicating imitation is one of the major learning mechanisms used by children (Hopper et al., 2010; Horner & Whiten, 2005; Whiten & Flynn, 2010). The pervasiveness of imitation occurred in spite of permission to deviate (“try anything you like”) and repetition of the goal (“see if you can get the egg out of the box”), alongside explicit linguistic cues as to whether or not the goal had been achieved. Faithful reproduction of modelled behaviour cannot be ascribed to task difficulty (known to increase imitation in

children: Williamson & Meltzoff, 2011; Williamson et al., 2008), as the majority of no-demonstration control participants were able to solve the task asocially. Three possible interpretations remain.

First, children are poor at evaluating efficacy of observed information (and indeed *personal* information when they reproduce the socially demonstrated method). Although the exit innovation findings in the current study stem from a small number of children, meaning this interpretation cannot be completely ruled out, the significant effect of experimental condition between the 0% and 75/100% groups does not appear to support the notion that children are poor at evaluating efficacy, nor do findings of prior research (Pasquini et al., 2007). Second, contradicting the actions of an adult demonstrator, by opting not to reproduce demonstrated behaviour, is an unfavourable option for children (due to adults' general level of perceived competence, Wood et al., 2012, or their modelling of normative behaviour). Yet previous evidence suggests that when there is sufficient reason to do so (i.e., the model is unreliable, actions are accidental, and behaviour is inefficacious), children will deviate (Birch et al., 2008; Carpenter et al., 1998; Williamson et al., 2008; Zmyj, Buttelmann, Carpenter, & Daum, 2010). Moreover, children *were* seen to deviate from the adult demonstrator, principally by trying out different tools (but less so the crucial exits). The third and final interpretation is that generating novel behaviour (as an alternative to imitation), capable of successfully altering the outcome of the task, was cognitively demanding following social demonstrations and that either the capacity or motivation to do so was lacking. Whilst not mutually exclusive, we propose that the competence interpretation (solely or in combination with a normative explanation given below) best explains the current findings - especially as the ability to use (innovate) a new exit increased from

8-9 years into adulthood - and aligns with previous research (children: Beck et al., 2011; callitrichids: Kendal, Coe, & Laland, 2005).

A number of important developmental progressions were uncovered in the present study, and suggest that reliance on social learning mechanisms is in part determined by age. In spite of the dominant imitation response, age effects were found regarding fidelity: 4- to 5-year-olds demonstrated more faithful imitation (enacting this strategy across more attempt trials) than older children. Imitation fidelity continued to decrease into adulthood. In the context of children's novel puzzle box interactions, wherein there is an explicit goal (tasks are not causally opaque), imitation thus appears to increase between the ages of 3 and 5 years (Flynn & Whiten, 2008; McGuigan, Whiten, Flynn, & Horner, 2007) before plateauing around the age of 6 years (present study). Consistent with Rakoczy, Hamann, Warneken, and Tomasello's (2010) observation of children deeming adults' demonstrated behaviour to be normatively correct, several children remarked, following demonstrations, 'so that's how you play the game'. This indication of rule learning or convention acquisition, together with children's general reluctance to depart from demonstrated behaviour, suggests normativity had a part to play in the findings. The age-driven decline in imitation could be facilitated by an age-driven decline in normativity and, relatedly, conformity (Walker & Andrade, 1996). Conformity also appears to be reduced for children, from the age of four years, when making judgements in more objective and less socially arbitrary domains (judging object *functions* as opposed to object *labels*; Schillaci & Kelemen, 2014).

3.4.2 Exit Innovation: The Rate and Influence of Observed Behaviour Efficacy

In line with cultural evolution theory (Boyd & Richerson, 1985; Richerson & Boyd, 2005) and previous experimental studies (Whiten & Flynn, 2010), in the current study a small minority of innovators emerged from a large population of ‘followers’. Exit innovations were produced by only 26 of 209 children following social demonstrations. The majority of children failed to recognise that exit innovations represented the sole way in which behaviour could be made more efficacious, such that a focus on behavioural *means* (tools used) as opposed to behavioural *outcome* prevailed (it could also be that the tools were highly salient to the children, by being the first object that was selected by the demonstrator, but less so to the more experienced adults). Those who continued with the socially demonstrated method when it was never efficacious (0% condition) or rarely efficacious (25% condition) may have found the social affiliation function of imitation (Over & Carpenter, 2012) rewarding. In future, it would be interesting to introduce a competition element whereby children would be encouraged to gain more stickers than the demonstrator.

Functional fixedness is a unique challenge for artefact tasks, and may account for the rarity of innovation. It describes a phenomenon whereby an object’s known conventional function prevents an appreciation of its alternative uses (German & Defeyter, 2000); in the case of the MMB, the top access points conventionally function as tool entrances, not capsule exits. The somewhat counter-intuitive developmental trend of functional fixedness (affecting 7-year-olds to a greater extent than 5-year-olds; Defeyter, Avons, & German, 2007) likely impedes the emergence of innovation; hampering its production just at the time that increasing cognitive

flexibility may better enable it. Although innovation increased with age, exit innovators were nevertheless very rare amongst even the oldest child age group. Executive functions may have a similar limiting effect. Inhibitory control skills develop significantly in the preschool years, but children do not show mature or advanced levels of performance in some executive abilities until aged 9-10 years or above (e.g., action inhibition: Simpson, Cooper, Gillmeister, & Riggs, 2013; planning; Tecwyn, Thorpe, & Chappell, 2014). Together with the late-developing inductive reasoning, permitting a variety of inferences to be made about a single item that fits multiple categories (Bright & Feeney, 2014), inhibiting prepotent responses and considering multiple possible outcomes prior to action will surely better enable innovation. With age, our participants became less restricted in their exit innovation capabilities – perhaps indicating the requirement for mature executive functions and more general cognitive maturity and flexibility to overcome the functional fixedness obstacle.

Rates of exit innovation increased from 8-9 years and were influenced by observed behaviour efficacy. Participants who experienced the lowest level of solution efficacy (the exit door was always locked) produced a greater number of innovative extractions than participants with a 75% or 100% level of observed solution efficacy. These latter two conditions were arguably the least conducive to innovation since they provided participants with a solution that always, or nearly always, worked. Yet, innovation is not just about solving a problem but exploring the world also. Indeed, Wood et al. (2013a) discovered that children are motivated to acquire multiple solutions to a problem even without the potential of a greater reward. In the current study, the 75% and 100% participants could plausibly afford to explore *more* than the 25% or 0% participants in the knowledge that they already

have a functional method in their repertoire, meaning potentially better ways of accomplishing the goal could be sought. It may be that children's performance was influenced by an adult model-based bias (a puppet was used for demonstrations in Wood et al.), but an alternative interpretation is suggested by the adult findings. Of the 12 adult participants who did not produce an exit innovation, 11 belonged to the 75% condition. Given that adults are not cognitively constrained in the same manner as children, it appears that they deduced no necessity in deviating from the socially demonstrated method when it was largely functional. Therefore, our results show it was likely necessity, not opportunity (implicated in the innovative tool use of various non-human primate species; Koops, Visalberghi, & van Schaik, 2014), that drove participants to innovate.

Individual learning from performing (exit) innovations was evidenced in two ways: repetition of an innovation, and/or production of more than one innovation. According to the former criteria, 10 of the 26 child exit innovators produced low-level innovations where there was no evidence of learning (note, however, that two of these individuals produced an exit innovation on the eighth trial, preventing subsequent assessment of learning). The greater propensity for innovation repetitions in adults (only 2 out of 33 producing low-level innovations) hints at the operation of more sophisticated learning and executive processes, but also at a potential disparity in approach to the MMB task. It is possible that adults were more goal-directed, prioritising the extraction of the capsule over the attempt trials, whereas children, when they chose to deviate from the social method and explore, did so in a more playful and 'random' manner. This is supported also by the varying complexities, or 'grades', of innovations when they were produced by the children. As an aside, in the context of the MMB task we cannot necessarily ascribe greater theoretical

significance to exit innovations that were accompanied by a novel tool and/or access point: the latter do not improve behaviour efficacy. However, in other contexts, innovation across all elements may be regarded as more insightful. Returning to the exit innovation findings, given children's capacity to incorporate newly presented task solutions into their behavioural repertoires (Wood et al., 2013a) we propose that it was the *generation* of alternative solutions, as opposed to the *switching* between them, which created difficulties with the current task.

3.4.3 Implications

Comparing our findings with those of Beck et al. (2011), where children succeeded at a novel hook invention task around 8 years of age, we provisionally suggest that innovation by modification and innovation by novel invention have somewhat distinct developmental trajectories. However, this can only be confirmed with further research including a variety of tasks. We also posit that, whilst innovation of any form is made challenging by a lack of certain cognitive abilities (particularly higher-level executive functions), individuals attempting innovation by modification are especially vulnerable to a canalisation or conservatism effect of prior social demonstrations. This is manifest in functional fixedness in tool-use tasks. Whilst the indication is that the task was more difficult in the absence of prior social demonstrations (fewer capsules were extracted in the no-demonstration than 100% condition), without these prior demonstrations participants were more exploratory and attempted a greater number of alternative task methods. Wood et al. (2013a) and Bonawitz et al. (2011) have similarly found observation and pedagogy to lead to restricted exploration and learning. The cost of quick and 'cheap' social information

acquisition is ultimately behavioural canalisation: becoming stuck on a particular method, and in turn blind to potential alternatives. Reducing the social context in experiments, to ascertain the extent to which innovation is inhibited by pedagogy, remains an imperative objective.

Laland (2004, p.11) speculated that, “If innovation is risky and associated with costs, then it is likely to be employed as a last resort... when socially learned strategies have proven unproductive”. Though there was no indication that innovation would be risky or costly for those in the low efficacy conditions of the current study (when the socially demonstrated method was unsuccessful and the reward could not be retrieved), our findings of rare and limited innovation, even in older and more competent individuals, do indeed suggest that children employ innovation as a last resort.

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Chapter 4

Behavioural innovation: State or trait?

Abstract

In order to gain a greater understanding of the evolution of human behaviour, we must better understand one of the mechanisms responsible for its variation: innovation. We address the hypothesis of whether individuals who innovate show consistency in this behaviour over time and over tasks. Twenty-three children, distinguished earlier by their innovative behaviour on a novel task (Multiple-Methods Box, MMB), were compared to twenty-three children who conversely demonstrated high levels of imitation fidelity (matched across age, sex, school, and condition in original study). A battery of tasks administered to the two groups to assess constructs related to innovation (social and asocial learning, inhibitory control, tool invention, cumulative problem solving, divergent thinking, verbal intelligence, and neophobia) revealed some consistency in innovation on puzzle boxes, with ‘innovators’ scoring higher on efficiency criteria than ‘imitators’. No other differences between the groups were found. In a second experiment, adults failed to exhibit a link between greater innovation, as measured also by performance on the MMB task, and the selected related constructs. Whilst certain child findings are suggestive of a ‘trait’ interpretation (i.e., consistent individual differences), the selectivity of the effect suggests innovativeness, of the type explored in this study, may be domain-specific. To the extent that the findings of this study are representative of innovation in general, we propose that, together with the adult findings and those of the original study, innovation appears more state- than trait-

based. Further investigation of the role of contextual and motivational factors in human behavioural innovation production is needed.

4.1 Introduction

Innovation is a complex phenomenon. Understanding more about its development, alongside its behavioural and cognitive correlates, will allow a deeper understanding of how it varies among individuals. Innovation is of critical importance to our survival as, together with high-fidelity transmission of information, it underpins our species-unique capacity for cumulative culture (Dean, Vale, Laland, Flynn, & Kendal, 2013). It is this mechanism to which we owe our remarkable technical and cultural sophistication, as well as our ability to adapt to environmental challenges. In this paper we focus on behavioural innovation (as opposed to cognitive innovation) which occurs in different forms. Innovations can appear as modifications of pre-existing behaviour, arising from a combination of social and asocial learning, or novel inventions, arising largely from asocial learning (Carr, Kendal, & Flynn, accepted: Chapter 2). These two forms of innovation are likely distinct in ways other than their input, for example their developmental trajectories, cognitive mechanisms, and primary barriers to their production, but what unifies them, certainly in childhood, is their apparent rarity (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; Carr, Kendal, & Flynn, 2015: Chapter 3).

The apparent rarity of innovation in childhood, when observed in experimental settings and compared with other learning strategies (such as imitation), can be attributed to a number of causes, including: developing cognitive capability or flexibility (Beck et al., 2011; Hanus, Mendes, Tennie, & Call, 2011), the ill-structured nature of innovation tasks (Cutting, Apperly, Chappell, & Beck, 2014), becoming canalised by existing behaviour (Flynn & Whiten, 2008; though see Wood, Kendal, & Flynn, 2013, 2015), an inability or disinclination to look beyond

known functions of objects (functional fixedness: German & Defeyter, 2000), adherence to perceived normativity of observed acts (Kenward, 2012; Keupp, Behne, & Rakoczy, 2013), and, plausibly, insufficient motivation. In apparent contrast to non-humans (Kendal, Coolen, van Bergen, & Laland, 2005), children also have a preference for acquiring information socially (Flynn, Turner, & Giraldeau, submitted; Wood et al., 2013) - potentially driven by a desire to affiliate with those who model such information (Over & Carpenter, 2013). Previously, for example, it has been observed that 3- to 5-year-old children do not attempt to innovate a novel solution to a tool-use task when they can acquire a suitable technique via observation (Flynn & Whiten, 2008). Even when children are not engaged in dyadic interactions, with their traditional learning expectations, and can explore a tool-use apparatus in free play for a substantial period of time, very few 3- to 5-year-olds innovate by producing alternative actions (Whiten & Flynn, 2010). It is not until later in childhood, around the age of 8 to 9 years, that innovations are more reliably produced (Beck et al., 2011; Carr et al., 2015; Hanus et al., 2011).

There is still much to understand about where and why children have difficulties with innovation. Research into children's imitation, including the extreme of the reproduction of causally irrelevant actions (Lyons, Young, & Keil, 2007), will prove helpful in this regard, as what viably supports imitation hinders innovation and vice versa. By understanding the barriers or psychological limits to innovation, as in the animal innovation field (Brosnan & Hopper, 2014), it will be possible to formulate appropriate interventions to assist children in overcoming them. The current study aimed to identify such enabling, or disabling, factors, through the examination of a number of potential correlates of innovation.

There are several reasons why innovation is both important and advantageous to assess in children. Not only are the cognitive and motivational systems that underpin innovation in childhood likely to be simpler than those that underpin innovation in adulthood (meaning the connections between innovation and its facilitators may be easier to explore), but it is probable that children are also less bound by social conventions and norms that can serve to increase imitative fidelity. Furthermore, examining innovation in childhood allows us to compare children's abilities with those of non-human animals (as in Hanus et al., 2011), addressing the evolutionary foundations of innovation in addition to its ontological foundations. This is imperative in the wider context and consideration of culture. The recent proliferation of innovation research with non-human species (see Hopper et al., 2014, and references therein) provides much insight and inspiration for analogous child research.

Although ostensibly rare in childhood, at least when compared with the rates at which children are seen to imitate, could it be that some children are naturally more innovative than others? Experiments with adults have been fundamental in establishing that, despite flexibility in humans' reliance upon social information, there are clear and consistent individual differences in how we use and value it (Molleman, van den Berg, & Weissing, 2014; Toelch, Bruce, Newson, Richerson, & Reader, 2014). Intuitively, those that use and value social information less, use and value individual information more, and in turn expose themselves to greater innovation opportunities. In the animal field, observations of individual variation in innovative behaviour have raised the possibility of an innovative heritable personality trait (e.g., Marchetti & Drent, 2000). Here, personality denotes consistent differences between individuals in their behaviour across time and contexts (Réale,

Reader, Sol, McDougall, & Dingemanse, 2007; Dingemanse, Kazem, Réale, & Wright, 2010). Crucially, the link between personality and innovation has been indicated both directly, due to consistency in an animal's own innovative ability (passerines: Morand-Ferron, Cole, Rawles, & Quinn, 2011), and indirectly, where individual differences in traits that contribute to innovation are related to individual differences in cognitive performance (learning speed of wild Cavies: Guenther, Brust, Dersen, & Trillmich, 2014, and feral guppies: Kendal & Brown, submitted; chimpanzee problem solving: Hopper et al., 2014). Furthermore, age (Massen, Antonides, Arnold, Bionda, & Koski, 2013), sex (Hopper et al., 2014) and social rank (Reader & Laland, 2001; Thornton & Samson, 2012) interact with innovative propensities, along with various other state-dependent traits (Sol, Griffin, & Bartomeus, 2012).

Determining whether a phenomenon is trait-driven, as the aforementioned research would suggest, is not a straightforward pursuit. Interactions between traits and 'states' (those factors that may drive innovation, such as hunger; Laland & Reader, 1999) must be considered, and even typically designated state-dependent factors, such as motivation, may actually contain a small stable individual trait component (Sol et al., 2012). Accurately partitioning states and traits may not be as imperative an objective as identifying what enables or inhibits the innovation process, but it has important ramifications for how we choose to subsequently assess innovation. Moreover, should innovation be found to be more of a 'trait' than 'state', this is arguably of greater evolutionary significance given that consistent phenotypic variation in non-humans has fitness consequences (Cole & Quinn, 2012; Dall, Houston, & McNamara, 2004) and may have an additive genetic basis (Morand-Ferron et al., 2011). Currently, it is unknown to what extent innovation is a trait in

humans. Certainly, innovators appear distinct in some biographic and personality characteristics (Rogers, 1995), and creativity, a precursor to innovation, is reliably and strongly predicted by, and correlated with, the personality trait of openness to experience (Feist, 1998; Kerr & McKay, 2013). It is plausible, therefore, that in the same manner in which research has deduced a correlation between individual differences in specific traits and *creative* output (Simonton, 2014), that similar outcomes may hold for innovation.

The current study is one of the first attempts to identify and assess the factors that underpin individual differences in children's behavioural innovation. We adopted a similar methodology to that of Overington, Cauchard, Côté, & Lefebvre (2011), who used a novel problem-solving task to distinguish 'innovator' and 'non-innovator' birds and subsequently compared them to investigate innovative characteristics. In a previous study (Carr et al., 2015), 26 out of 209 children were identified as 'innovators' by producing at least one novel and successful solution on a tool-use task following the social demonstration of a method. Here, we matched these 'innovators' with children who had demonstrated high levels of imitation fidelity ('imitators'), to investigate whether the groups were clearly distinguished on tasks conceptually related to innovation, in line with a 'trait' interpretation of innovation, or whether there would be little consistency within the groups, indicative of a 'state' interpretation. To answer such questions, it was necessary to administer a wide range of tasks, each with a theoretical and/or empirical rationale as to why the assessed construct might relate to innovation, or make an individual more or less innovative. The constructs are overviewed in Table 4.1.

Table 4.1

Constructs Examined in the Current Study, Their Rationale for Inclusion, and Research Questions Investigated

Construct	Rationale for Inclusion	Research Questions
Social Learning	Social and asocial learning co-vary in some animal species (e.g., pigeons: Bouchard et al., 2007; primates: Reader & Laland, 2002). Whilst non-human animals typically show a preference for asocial learning (Rieucan & Giraldeau, 2011), humans appear to individually differ in their preference for, or use of, <i>social</i> information (Molleman et al., 2014; Rogers, 1995; Toelch et al., 2014).	Do innovators have a consistent preference for innovation (and imitators for imitation), or flexibly switch between the two learning strategies?
Asocial Problem Solving	Asocial learning performance on novel foraging tasks can predict the likelihood of an individual being an innovator (first to solve a task; starlings: Boogert et al. 2008). Moreover, greater and more diverse exploratory behaviours, as well as exploration persistence, allows for more successful problem solving (Benson-Amram & Holekamp, 2012; Huebner & Fichtel, 2015; Overington et al., 2011; Thornton & Samson, 2012).	As asocial learning leads to innovation, do innovators achieve significantly higher asocial problem-solving scores than imitators?
Inhibitory Control	Inhibitory control is linked to innovation in wild meerkats (Thornton & Samson, 2012): those most successful on novel food extraction tasks were able to inhibit ineffective and prepotent responses across trials. By doing so, alternative effective solutions can be generated. Children have difficulties with inhibition, particularly action inhibition, throughout childhood (Simpson et al., 2013).	If inhibition is a key component of innovation, do innovators show superior abilities in this regard?
Invention	Innovation by modification (of a behaviour previously observed/already in an individual's repertoire), and innovation by novel invention are theoretically distinct forms of innovation (Carr et al., accepted). Are they distinct in practice?	Do children perform similarly on modification and invention tasks?
Cumulative Problem Solving	Cumulative culture is typified by the increasing complexity or efficiency of behaviour/knowledge/technology from one generation to the next (Boyd & Richerson, 1996), with innovators introducing new behavioural modifications. On an individual level, the ability to build upon one's knowledge permits innovative solutions to be reached.	Do innovators show an enhanced ability to build upon their existing knowledge?
Divergent Thinking	Divergent thinking involves generating many possible ideas or solutions to a	Are innovators distinguished by

	problem (Guilford, 1959), without the requirement they are good, useful or workable (Runco & Acar, 2012). However, amongst many ideas, there may be one that is both original and valuable ('creative': Picciuto & Carruthers, 2012), potentially leading to an innovative behavioural outcome.	their generation of more ideas?
Verbal Intelligence	Intelligence is recognised as a correlate of creativity (Rogers, 1995), though it is unclear whether this is an effect of general intelligence or more specific expertise in the domain creativity is assessed.	Do innovators and imitators differ in their verbal intelligence (as a proxy for general intelligence)?
Neophobia	Neophobia, the fear of novel objects (Greenberg, 2003), will intuitively impede, or slow, the production of novel behaviour utilising them. It is identified as a major inhibitor of innovation in non-humans (Brosnan & Hopper, 2014; Day et al., 2003).	Are innovators less neophobic than imitators?
Social Status	Social rank may serve to enhance the appearance of neophobia (e.g., through low-ranking individuals' fear of aggression from higher-ranking individuals) or diminish it (e.g., those of higher competitive rank contacting and solving tasks first; Boogert et al., 2008). In chimpanzees, those of low social rank are more frequently reported as innovators (Reader & Laland, 2001) presumably due to increased necessity of doing so.	Are innovators of a higher or lower social status than imitators?
Boldness- Exploration Traits	In a similar manner to neophobia, boldness and exploration may facilitate innovation. Assessments of these, and other, traits correlate highly between knowledgeable observers of individuals (chimpanzee keepers/staff: Freeman et al., 2013; teachers and parents of children: Flynn & Whiten, 2012), making the use of such ratings valid.	Are innovators rated higher than imitators in boldness and exploration (and related traits) by a knowledgeable observer?

Here we assess whether a group of pre-defined innovators and imitators show significant differences across our critical measures. Between-group consistency in performance differences on tasks related to the constructs would support a ‘trait’ of innovation, whilst a lack of between-group consistency would support a ‘state’ of innovative behaviour.

4.2 Experiment 1

4.2.1 Method

4.2.1.1 Participants & design.

Forty-six children (24 males) from three primary schools in the North East of England participated. All children had, approximately six months earlier, taken part in a study using a novel tool-use task (the Multiple-Methods Box, MMB; Carr et al., 2015) and were selected for the current study on the basis of their behaviour with the MMB. Children were coded as innovating on the MMB task if they removed a reward from inside it using a different exit to that observed during social demonstrations. Although the use of a novel tool and/or access point for the tool also technically constituted an innovation, we focused on *exit* innovations as it was the exit that was variable in its effectiveness and required altering to reliably retrieve the reward. The 26 children who innovated in this way were compared to 26 children who displayed full, or high, levels of imitation fidelity on the MMB (never produced an exit innovation and imitated the socially demonstrated method on at least five of the eight attempt trials; mean number of trials on which imitation occurred = 6.48,

compared to a mean number of 2.22 imitation trials for those who innovated). Matched pairs, containing an innovator and imitator, were created according to similarity in age, sex (two pairs were mixed sex owing to unsuitable alternative matches), condition (to which they were assigned in Carr et al., 2015) and school. Group allocation was known only to the experimenter (KC). Both groups received identical experimental tasks and procedures. Three pairs of children were not included in the final sample due to an absence of follow-up parental consent, leaving 23 ‘innovators’ (13 male, M age = 8 years 4 months (8;4), SD = 19 months) and 23 ‘imitators’ (11 male, M age = 8;5, SD = 18.5 months). There were no significant differences in age ($t(44) = -0.07$, $p = .94$) across the two groups.

4.2.1.2 Materials & procedure.

To examine group differences in performance on constructs hypothesised to relate to, or facilitate, innovation, a battery of tasks was administered (see Table 4.2). All tool-use tasks were placed on a table directly in front of participants, and any demonstrations provided were from the child’s perspective of the task. The first five tasks were run in a morning session and the following three tasks in an afternoon session, to reduce boredom and fatigue. Whilst the majority of morning and afternoon sessions took place on the same day, on occasion there was a delay of one or two days between sessions owing to lesson conflicts or child absence. Tasks were administered in the same order for each participant, and are shown in Table 4.2 alongside the outcome measures recorded (see Supplementary Material (Appendix Item 2) for further task details, individual procedures, and puzzle-box Figures). Upon completion of all tasks, children’s favourite lessons and after-school activities were

noted. All children were rewarded with a large sticker irrespective of their performance.

Table 4.2

Tasks Administered for Assessed Constructs and Their Outcome Measures

Task	Description	Outcome Measures
<i>Social Learning</i> Transparent glass-ceiling box (Horner & Whiten, 2005)	Two glass-ceiling box demonstrations featuring causally irrelevant and relevant actions, followed by five attempts	Total irrelevant actions copied, summed across five attempt trials (max. possible = 55)
<i>Asocial Problem Solving</i> Pan-pipes (Whiten, Horner, & de Waal, 2005)	Tool-use task in which the goal is to retrieve a capsule by moving an obstruction (cube-shaped block) behind which the capsule rests in upper of two pipes; no demonstrations, maximum of 15 attempts or 5 minutes	Number of methods discovered* (max. = 3) Latency to first reward retrieval, timed from first apparatus interaction
<i>Inhibitory Control</i> Luria hand game (Luria, 1973)	Sixteen trials requiring production of opposite action to that of the experimenter (fist or finger gesture)	Total correct first responses (max. = 16)
<i>Invention</i> Hook task (Beck et al., 2011)	Materials provided (pipecleaner, piece of string, two wooden sticks) with the aim of retrieving a bucket from a narrow Perspex tube; three minute time limit applied	Hook score (0: unsuccessful; 0.5: hook or T-shaped tool attempted; 1: hook or T-shaped tool successfully manufactured/implemented)
<i>Cumulative Problem Solving</i> Cumulative box (Dean et al., 2012)	Rewards of increasing desirability to be gained by solving three task stages, with success on highest (and more difficult) stage only achieved through success at lower (and easier) stages; same actions could be performed on identical left and right sides of box; three minutes allowed per stage	Cumulative score (1 for each stage; max. = 3) Latency to first solution, timed from first box interaction (left or right side of box) Latency to task completion* (left and right side of box)
<i>Divergent Thinking</i> Alternate uses task (Guilford, 1967)	Alternate uses to be generated for two common objects (paper cup and paperclip); items provided as visual aids; verbal responses noted by experimenter	Scores for fluency (number of responses), flexibility (categories), elaboration (amount of detail) and originality (rarity of responses), summed across two items Originality score corrected for fluency*
<i>Verbal Intelligence</i> British Picture Vocabulary	Instructed to point to one picture, from a choice of four, which corresponded to a word spoken by experimenter	Standardised score

Scale (Second edition; Dunn, Dunn, Whetton, & Burley, 1997)		
<i>Neophobia</i> Sticker disc (Wood et al., 2015)	Presented opportunity to play with ‘new toy’; maximum of 5 minutes to retrieve a sticker by aligning holes in circular panel on top of box with circular holes of compartments, and utilising plastic tweezers attached to box	Spontaneous prior reference and/or touch Latency to first touch, timed from end of experimenter instructions* Mean task latency

Notes. *Where multiple measures were recorded for a task, an asterisk denotes the measure selected as the critical representation of the construct. As not all participants were successful with the Pan-pipes, cumulative box and sticker disc task, ceiling values of 300s, 540s and 300s, respectively, were applied (analyses with and without pairs containing ceiling values produced qualitatively similar results). The alternate uses originality score was calculated by comparing each response with those made by all participants. Responses that were given by 2-5% of participants were considered unusual and allocated one point, whilst responses given by 1% of participants were considered rare and allocated two points. Responses had to be considered appropriate uses to be scored (e.g., a response of 'bending' a paperclip was not accepted, unless qualified by further description of what it could be bent into). Although participants were matched as closely as possible for age, this was not exact and so the standardised BPVS score was calculated as opposed to the raw score.

Two additional measures were collected from children's class teachers. First, to gain insight into children's social status, teachers were asked to rank participating children (out of their total class size) in line with four statements of popularity and dominance. These statements were as follows: 'is friends with a significant number of other individuals', 'is friends with a smaller number of more influential individuals', 'often initiates conflicts with other children and dominates resources', and 'is able to acquire and monopolise resources over other individuals without using aggression'. Second, teachers were asked to complete the Child Behaviour Questionnaire (CBQ). Although the CBQ, which measures children's temperament, was originally designed as a parental measure, the responses of parents and teachers

have been shown to correlate (Flynn & Whiten, 2012). Only theoretically-relevant subscales were included (activity level, attentional focusing, attentional shifting, impulsivity, inhibitory control, and shyness), and individual statements removed if not relevant to a classroom context. Our final version of the CBQ contained 65 items. The return of ratings and questionnaire information from teachers was approximately 50% (corresponding to a roughly equal number of innovators and imitators).

4.2.1.3 Scoring and inter-rater reliability.

The experimenter, KC, coded 100% of the sample from video tape. The outcome measures, and how they were scored, are detailed in Table 4.2. An independent observer, blind to the specific hypotheses of the study, coded 20% of the sample (observational measures). Cohen's Kappa scores of all measures, excepting that of the Luria hand game, were 0.89 or above, showing an excellent level of agreement. Inter-rater reliability for the Luria hand game was low and, though several discrepancies were resolved between coders, it was determined on the basis of errors in the administration of the task (due to the complex nature of the pseudo-random protocol) combined with clear subjectivity in children's responses (most children did not assume a neutral hand position inbetween fist and finger gestures, thus making small adjustments to gestures difficult to categorise) that the task be excluded from the analyses.

4.2.1.4 Statistical methods.

Where data were found to be non-normally distributed, non-parametric tests were used. To avoid inflating the Type I error rate as a result of multiple comparisons, a Bonferroni correction was applied by dividing the critical significance level of .05 by the total number of tests conducted per task (as opposed to across tasks, given that the tasks were examining theoretically different behavioural constructs). Probability values reported with an asterisk indicate the significance level required to reject the null hypothesis following this correction. All analyses reported are two-tailed.

4.2.2 Results

The results are presented in five sections. First, we explore between-group (innovators vs. imitators) differences on the task measures. This is followed in the second section by a comparison of performances within matched pairs across tasks, and in the third section by an exploration of predictor variables. We then consider consistency in innovators' and imitators' overall behaviour, and finally the additional measures obtained from teachers (popularity/dominance ratings and CBQ) and children (preferred lessons and after-school activities).

4.2.2.1 Do innovators and imitators significantly differ in their task performance?

A series of analyses were undertaken that compared the performance of innovators and imitators on each of the task measures reported in Table 4.2 (excluding the Luria hand game). The outcome of these analyses, specifically the probability values obtained, can be seen in Table 4.3. Only two significant group differences were revealed, which remained significant following the Bonferroni correction. Innovators discovered significantly more methods with the Pan-pipes task ($Mdn = 2$, $SD = 0.79$) than imitators ($Mdn = 1$, $SD = 0.77$; Mann-Whitney $U = 167$, $z = -2.30$, $p = .02$, $p^* = .025$), and innovators reached the first solution of the cumulative box (left or right side) in a significantly shorter period of time ($Mdn = 2$, $SD = 13.50$) than imitators ($Mdn = 11$, $SD = 40.12$; $U = 156$, $z = -2.42$, $p = .016$, $p^* = .02$).

Table 4.3

Comparing the Performance of Innovators and Imitators on Task Measures, with Mann-Whitney U Tests

	Innovators		Imitators		p
	Mean (SD)	Median	Mean (SD)	Median	
<i>Social Learning: Glass-Ceiling Box</i> Irrelevant action score	37.74 (17.49)	40	43.30 (15.67)	52	.22
<i>Asocial Problem Solving: Panpipes</i> Methods discovered	1.57 (0.79)	2	1.04 (0.77)	1	.02*
Latency to first retrieval	87.87 (88.03)	50	121.17 (113.01)	75	.45
<i>Tool Invention: Hook Task</i> Hook score	0.39 (0.48)	0	0.48 (0.44)	0.5	.47
<i>Cumulative Problem Solving: Cumulative Box</i> Cumulative score	2.70 (0.70)	3	2.61 (0.84)	3	.72
Latency to first solution (L or R)	8.61 (13.50)	2	27.13 (40.12)	11	.016*
Latency to task completion (L&R)	220.30 (181.83)	150	269.30 (211.35)	130	.65
<i>Divergent Thinking: Alternate Uses</i> Fluency score	8.17 (4.56)	8	7.52 (4.82)	6	.50
Flexibility score	5.57 (2.13)	6	5.09 (2.04)	5	.38
Elaboration score	2.26 (3.52)	1	1.74 (2.56)	1	.82
Originality score	2.48 (2.45)	2	2.70 (2.77)	2	.90
Corrected originality score	0.28 (0.22)	0.3	0.31 (0.26)	0.27	.83
<i>Verbal Intelligence: BPVS</i> Standardised score	104.76 (13.24)	104	100.61 (10.96)	100	.26
<i>Neophobia: Sticker Disc</i> Latency to first touch	1.65 (2.12)	1	1.39 (1.90)	1	.73
Average task latency	76.00 (45.01)	65	87.59 (57.89)	101	.89

* $p < .05$. $N = 46$ for all measures excluding BPVS standardised score ($N = 44$, exclusion of two innovators due to lack of task engagement). Full statistical information is provided in the text for significant tests.

It is interesting to note a number of further findings that arose. There was a significant negative correlation between the number of methods discovered in the Pan-pipes task and latency to first reward retrieval ($\tau = -.40$, $p = .001$), such that those who discovered the most methods were the quickest to achieve their first asocial solution to the task. This was mirrored in the cumulative task, with a significant negative correlation between cumulative score (number of stages solved) and the latency to solution of the first stage (left or right side of box): $\tau = -.26$, $p = .04$. Furthermore, a cross-over between these tasks was demonstrated with a significant negative correlation evidenced between Pan-pipes methods and latency to first solution with the cumulative box: $\tau = -.36$, $p = .003$. With regard to the spontaneous prior reference and/or touch of the sticker disc (Table 4.2), a roughly equal number of innovators and imitators referenced the sticker disc (five and seven, respectively) and touched the sticker disc (two and three, respectively) prior to its formal introduction.

4.2.2.2 Across tasks, do innovators or imitators score more highly?

Looking exclusively at the single measures identified as the most critical representations of constructs (Table 4.2), we investigated whether further group differences would be revealed by comparing the number of occasions innovators outperformed imitators or vice versa, across tasks, using exact binomial tests. We operationalised more efficient performance (as referenced in Table 4.4) as: lowest irrelevant action score with the glass-ceiling box, most methods with the Pan-pipes task, highest score with the hook task, shortest latency to task completion with the cumulative box, highest originality score (corrected for fluency) with the alternate

uses task, highest standardised BPVS score, and shortest latency to first touch with the sticker disc.

Table 4.4

Comparing Matched Pairs of Innovators and Imitators Across Tasks, Using Exact Binomial Tests

Task	Frequency		<i>p</i>
	Innovator More Efficient	Imitator More Efficient	
Glass-ceiling box	15	4	.02
Pan-pipes	11	3	.057
Hook task	5	7	.77
Cumulative box	12	10	.83
Alternate uses	10	13	.68
BPVS	10	8	.82
Sticker disc	8	7	1

Note. Pairs that achieved equivalent scores are excluded, thus accounting for the discrepancy in total frequencies across tasks. Two pairs of children were excluded from the BPVS analysis owing to two children's lack of engagement with the task.

As a group, innovators outperformed imitators in producing fewer causally irrelevant actions with the glass-ceiling box ($p = .02$). Although only approaching significance ($p = .057$), overall innovators also discovered a greater number of methods with the Pan-pipes task.

4.2.2.3 Which, if any, variables predicted innovator-imitator group membership?

In order to discover whether any of the variables identified as critical representations of the constructs were able to predict innovator-imitator group membership, binomial generalized linear mixed models (GLMM) with a logit link function were used to analyse our data. As the analysis excluded two of the innovators, owing to their missing BPVS data, it was necessary to also exclude their matched pairs. Thus, data from 21 pairs of children were entered. The seven critical representations of constructs were entered as fixed effects (explanatory/predictor variables), and children's predetermined group (innovator/imitator) as the target dependent variable. As children were matched according to age, sex and school, these were not entered as random effects. The resultant model indicated innovator or imitator group membership could not be significantly predicted by any of the explanatory variables (see Supplementary Material (Appendix Item 2) for additional details regarding the statistical model).

4.2.2.4 Are innovators and imitators consistent in their overall behaviour?

To examine consistency in how innovators and imitators performed between tasks, participants were ranked on the three task measures that revealed significant group differences: irrelevant action score with the glass-ceiling box, methods discovered with the Pan-pipes, and latency to the first solution with the cumulative box. A higher rank denoted greater efficiency on the task (i.e., lower irrelevant

action score, higher number of methods, and lower latency). A Kendall's W test did not reveal significant agreement between participants' ranks on these measures ($W = .009$, $\chi^2(2) = .84$, $p = .66$), and indeed, separating by group, innovators and imitators demonstrated the same (low) level of agreement; that is, they did not consistently achieve similar ranks on tasks.

4.2.2.5 Are innovators and imitators distinguished by biographic and child- or teacher-report measures?

No significant differences were found between innovators and imitators on the following measures: sex, sibling number, selected CBQ subscales, teacher-rated popularity and dominance, preferred lessons and extracurricular activities. The rate of return of teacher measures (CBQ and popularity/dominance ratings) was, however, only around 50%, meaning these particular findings should be interpreted with caution.

4.2.3 Discussion

The results reported throughout this section do not support the notion of distinct innovator and imitator groups within our sample and thus of an innovation trait. Overall, there was very little to distinguish the two groups. Interestingly it was the puzzle-box tasks (glass-ceiling box, Pan-pipes, and cumulative box), that is those resembling the original MMB task, which *did* elicit performance differences. Whilst this suggests domain-specificity in innovativeness, it remains to be seen whether the constructs that are associated with innovation change or become more evident with

age. Could it be that individuals more strongly resemble innovators and imitators later in life? The next experiment investigates this possibility with adult participants.

4.3 Experiment 2

4.3.1 Method

4.3.1.1. Participants & design.

Thirty-one Durham University students participated (15 male, $M = 20$ years 9 months (20;9), range 18;6-27;7), all of whom had previously completed the MMB task (Carr et al., 2015). Given that the majority of these adults (20 out of 31) produced at least one exit innovation in the MMB task, it was not possible to group participants in the same manner as Experiment 1. Therefore analyses were conducted within the adult group as a whole, following a correlational design. As no effects of sex or age were found, these were not investigated further.

4.3.1.2 Materials & procedure.

In an effort to reduce ceiling effects owing to adults' significantly enhanced cognitive abilities, it was necessary to replace some of the tasks listed in Table 4.2. The replacements were as follows (as before, Figures of puzzle boxes and additional task/procedural details are provided in Supplementary Material (Appendix Item 2)).

Asocial problem solving: Sweep-drawer-lever box. The sweep-drawer-lever box (SDLB: Wood et al., 2013) was selected in place of the pan-pipes to allow for a

greater diversity of exploratory behaviours (methods can be combined and order of actions varied). Like the pan-pipes, it is a puzzle box into which a capsule (containing a sticker) is inserted and held in place by defences. Three box mechanisms can be used to release the reward. The following outcome measures were recorded: number of methods discovered (selected as the critical representation of this construct), latency to first retrieval (timed from first box touch), and number of method repetitions (relating to the specific combinations of actions).

Inhibitory control: Stop-it. The Luria hand game was replaced with a computer-administered stop-signal task (Logan & Cowan, 1984; Stop-It: Verbruggen, Logan, & Stevens, 2008). An overall stop-signal reaction time was calculated for each participant, capturing latency of the stop process and hence inhibitory ability.

Invention: Candle problem. The candle problem was developed as a test of problem solving (Duncker, 1945, as cited in German & Defeyter, 2000), requiring participants to attach a candle to a vertical board with only a box of tacks and a book of matches whilst ensuring that the candle does not drip wax onto the surface below. Though not directly analogous to the hook task administered to children, it similarly requires the innovative use of materials to reach a solution. A score of 0 was given if unsuccessful, 0.5 if the participant achieved partial success (attaching the candle directly to the board but allowing dripping of wax, counter to task instructions), and 1 if the optimal solution of a candle shelf was produced. Participants had a maximum of three minutes with this task.

The BPVS and sticker disc task, measuring verbal intelligence and neophobia, were excluded and not replaced.

4.3.2 Results

Generalized linear mixed models (GLMM, Poisson distribution with Log link) were applied to the data to investigate whether greater innovation with the MMB could be predicted by performance with our other task measures. Critical representations of constructs were entered as fixed effects. Given that adults did not undergo the same matching procedure as children, the condition to which adult participants were originally assigned with the MMB task (0% efficacy of social information vs. 75% efficacy of social information; Carr et al., 2015) was also entered as a fixed effect. The two measures of innovation with the MMB (exit innovation attempts including, and excluding, repetitions) were entered into separate models. The latter target variable (exit innovations excluding repetitions) produced the model with the best fit, as determined by the Corrected Akaike Information Criterion (104.79 versus 161.85), yet the model and all fixed effects were found to be non-significant (the fixed effect of Condition was approaching significance; $p = .075$). Entering exit innovations including repetitions as the target variable also produced a non-significant model, but the fixed effect of Condition was found to be significant: $p = .03$ (see Supplementary Material (Appendix Item 2) for further information relating to both models). Specifically, participants in the 0% condition (for whom the exit door was always locked, preventing reward extraction via the socially demonstrated method) were 3.58 times more likely to produce exit innovations than participants in the 75% condition (for whom the exit door was unlocked on 75% of trials; exp. coefficient = 3.58, $t = 2.31$, $p = .03$). This result reaffirms that reported in Carr et al., 2015 (Chapter 3).

4.3.3 Discussion

The results indicated that greater innovation on the MMB task could not be predicted by any of our other task measures (examining the constructs of social learning, asocial problem solving, inhibitory control, invention, cumulative problem solving, and divergent thinking). Rather, participants' allocated condition in the MMB task generated the only significant effect. It thus appears that, for our study, a context or state-based interpretation of adults' innovation is more appropriate than a trait-based one.

4.4. General Discussion

We investigated whether individual differences in behavioural innovation, as measured by performance with a novel puzzle-box task (the MMB), were underpinned by or related to individual differences in a number of constructs of theoretical and/or empirical relevance to innovation. This was achieved in a child sample (Experiment 1) by comparing matched groups of pre-established innovators and imitators (from Carr et al., 2015) on a battery of tasks. Findings from Experiment 1 suggested behavioural consistency in puzzle-box contexts, both across alternative tasks and over time (MMB and alternative task administration separated by six months). Whilst perhaps indicative of a stable innovative personality trait, the selectivity of the effect suggests innovativeness, of the type explored in this study, may be domain-specific. No other discernible differences between the groups were uncovered. Experiment 2 found no relation between innovation with the MMB task and other theoretically and conceptually-related measures in adult participants,

casting doubt on the possibility of innovation-as-trait and raising important questions about the role of context and motivation in innovation production (to which we return later in the Discussion).

The division of individuals into one of two groups based on their propensity to learn socially or individually is not new. Studies using computer-based tasks for example, such as that of Kameda and Nakanishi (2002), have distinguished ‘information scroungers’ (social learners) and ‘information producers’ (individual learners). However, how far these categorisations generalise and extend beyond single studies, in terms of their longer-term applicability to the individuals, remains to be seen. Non-human animal research has complemented this line of enquiry by uncovering apparent animal personality types, some of which are implicated in innovatory propensities. The emerging impression here is that an individual may fall under the category of producer *or* scrounger, or conformist *or* maverick (Efferson, Lalive, Richerson, McElreath, & Lubell, 2008), based on their preference for a particular learning strategy in a given study. Yet we also know that, in theory and via mathematical simulations, the most adaptive learner is one who selectively uses social *and* asocial information (Hoppitt & Laland, 2013), trading off one for the other dependent upon the environment, situation and context (Kendal et al., 2005). We set out to investigate whether children and adults: (i) display a consistent preference for an innovative learning strategy in line with a ‘trait’ interpretation, and are thus more likely to exhibit the associated innovation constructs overviewed earlier; or (ii) display more fluid preferences, in which case motivation and context (‘states’) will be key. Taken overall, and in combination with findings from our first study (Carr et al., 2015), the results are in favour of the latter proposal. Only a few of

our measures were able to marginally hint at some stability in individual behavioural differences, and only within our child sample.

Innovators within our child sample were distinguished from imitators in three ways. First, they appeared to display reduced adherence to social information and, with this, an ability and/or desire to increase efficacy of behaviour. This was demonstrated initially with the MMB by deviating from the often-unreliable observed exit, and again with the glass-ceiling box by imitating fewer irrelevant actions than their matched pairs. Second, greater aspects of exploration and problem solving were evident on both the MMB (in terms of the discovery of one or more alternative exits) and the Pan-pipes task (wherein more methods were produced). Third and finally, these individuals appeared to be faster explorers in reaching the first stage of the cumulative box, though not all stages, in a shorter period of time. Thus we have provided partial evidence for a propensity of our innovator children to engage in greater, and faster, individual learning, mirroring the same relation found in the animal innovation field (e.g., Boogert, Reader, Hoppitt, & Laland, 2008; Kendal & Brown, submitted) and consistent with evidence that human individuals vary in their use of social information (Rogers, 1995; Molleman et al., 2014; Toelch et al., 2014). With regard to exploration and problem solving, the two are strongly linked to innovation. Indeed, in the physical tool-use domain, novel problem solving is its hallmark. Exploration is qualitatively distinct, but integral, to innovation (Reader & Laland, 2003): the more you explore, the more likely you are to discover or chance upon novel behaviours and information. To date, research has provided much insight into the effect of exploration versus direct instruction on children's learning (e.g., Bonawitz et al., 2011; Wood et al., 2013), yet there is further potential for the exploration-innovation relation, specifically, to be addressed.

Interestingly, there was nothing to distinguish innovators on two of our additional tool-use tasks: the hook invention task, and the sticker disc (neophobia is discussed in a subsequent section). Failure to find differences between our groups using the hook invention task (innovators were no more likely to solve it than imitators) suggests that innovation by modification (as measured with the MMB) and innovation by novel invention (as measured with the hook task) are two distinct forms of the phenomenon, with different difficulties associated with each. This will, however, require replication with further tasks for a more definitive conclusion to be drawn. The other task measures which showed no effect were those pertaining to divergent thinking and verbal intelligence. In the light of individual differences in divergent thinking from the age of 2 years (Bijvoet-van den Berg & Hoicka, 2014), and its conceptual similarity to innovation, it was surprising that our groups did not differ in this measure. Critically, however, its assessment in the verbal rather than physical domain may be responsible; effects may not translate. We, likewise, found no difference between our groups on our proxy measure for general intelligence, suggesting it is domain-relevant expertise that is important for creativity and innovation (Simonton, 2000), something the BPVS task fails to capture. Additionally, having greater verbal proficiency may facilitate the verbal generation of ideas (the correlation between divergent thinking and BPVS performance was approaching significance) without necessarily facilitating their *physical* generation and implementation.

Before proceeding to discuss the adult findings, the domain-specificity and non-generality of the findings necessitate emphasis. Whilst puzzle-box tasks bear basic resemblances, there are an increasing number used in the social learning field that address highly similar empirical questions. It is, therefore, a reassuring finding

to discover some consistency in the way in which they are approached by children, a consistency which extends over time (a six-month testing gap for child participants). Nonetheless, the measures within our puzzle boxes were evidently very specific, and did not correlate across puzzle boxes as might have been expected. For example, innovators appeared to be faster explorers in reaching the first stage of the cumulative box in a shorter space of time, but were no quicker than imitators at discovering their first method on the Pan-pipes task or retrieving a sticker from the sticker disc. The exploration of alternative interpretations for our non-significant findings is imperative given it would be unwise to dismiss the various constructs' relevance to innovation on the basis of specific, and singular, measures (in which we include that of the MMB). Multiple methods and measures are vital to rule out chance performances and the operation of other extraneous factors (Thornton, Isden, & Madden, 2014). We note, however, that the lack of significant findings do not appear to be due to floor or ceiling effects in children's task performance (see Table 1 in Supplementary Material (Appendix Item 2)).

Adults' performance on the MMB could not be predicted by any of our task measures, only by the condition to which they were assigned with the MMB. This is a strong indication that adult participants were driven to innovate not by inherent personality differences, but by necessity (Reader & Laland, 2003); a 'state' induced by uncertainty in the reliability of social information. Unlike children, all adults may possess the capacity to innovate but whether they do so is context-dependent. This could still produce the producer-scrounger dynamics we know underlie stable populations, along with reliably 'innovative' individuals: they may better discern need and have the appropriate expertise to act upon it. Our small and homogenous adult sample (all being young adults, and University students) prevents the

extrapolation of our findings to adults as a whole. Individual differences in innovatory propensities may be more evident in older adults and adults with more diverse backgrounds.

It is important that we acknowledge a number of limitations in our current study; most pertinently, that of the size of our child sample. While our small sample was necessitated, given only 26 innovators emerged from our original sample of 256 children, the pattern of findings requires replication in a larger sample. It is possible that further, and a greater variety of, effects would have been seen with a larger number of participants. Moreover, owing to time constraints and potential boredom for our participants, we were limited in the number of tasks that could be administered, meaning the constructs we selected were not comprehensive. Nevertheless, to our knowledge this study is one of the first to follow up children who appeared to differ in their propensities for innovation and imitation and investigate potential explanatory factors. In future research, it will be essential to establish the factors that facilitate innovation at varying developmental stages, beyond the relatively small age range studied here, and conduct vital longitudinal studies.

Extending research beyond solitary settings into social ones will also better allow situational and dispositional effects to be discerned (Massen et al., 2013; Morand-Ferron et al., 2011), including those of social dominance, rank, competition, persistence and neophobia. Though we attempted to incorporate these into the current study, administering tasks in groups introduces free choice into the procedure (such as when to approach a new task, if at all). Prior research indicates that more popular and dominant children have more success at solving tool-use tasks in these contexts (Flynn & Whiten, 2012), and hence may be the first to innovate. With the

existing set-up, the effects of rank and/or neophobia could have been largely masked by perceived pressure to act upon presented objects. Similarly, it was not possible to truly measure persistence (or lack of) unless participants opted to finish a task early which was a rare occurrence. Both neophilia and persistence are implicated in appearances of innovation in non-human animals. The social dynamics of innovation that operate in the ‘real’ world are likely to be far more complex than we presently understand. Group settings are imperative for capturing the range and diversity of children’s natural innovation along with its context-dependency, as are more informal learning environments such as museums and ‘makerspaces’ (e.g., Halverson & Sheridan, 2014).

Finally, in noting limitations, we echo concern arising from the non-human field regarding the way in which individual differences are measured and cognitive variability interpreted (Rowe & Healy, 2014; Thornton et al., 2014). Not only must we remain vigilant to subjectivity in interpretations of ‘better’ performance (slower performance, though typically less valued, may reflect deeper learning and the consolidation of experiences; Marchetti & Drent, 2000; Rowe & Healy, 2014), we must be consistently mindful of alternative and simpler explanations for variability in performance such as motor diversity (Griffin, Diquelou, & Perea, 2014), memory or motivation. We are not able to rule out the possibility that our innovators and imitators were initially distinguished by these factors, as opposed to those individual differences we measured.

Ultimately, our results do not support a trait-based interpretation of innovation (of the type explored in this study), given we did not find our groups to be distinguished by the majority of constructs we assessed, but they do hint at some consistency in children’s behaviour on domain-related tasks. Variation in children’s

use of social versus individual learning demonstrated here, and children and adults' sensitivity to context (as in Carr et al., 2015), are identified as two potential major factors in innovation production. With increasing insight into such factors, we move closer towards a more comprehensive understanding of the innovation phenomenon and, thus, how human behaviour evolves.

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Chapter 5

Can children's innovation be facilitated by normative information?

Abstract

This study tested the hypothesis that normative language can be used to cue innovative behaviour in a similar manner to imitative behaviour. Children aged 8-9 years ($N = 84$) were presented with the Multiple-Methods Box (MMB), a novel puzzle box from which a reward can be extracted using different tools, access points and exits. Prior to attempts with the task, children received one of three verbal frames. Two of the three frames were designed to promote behavioural normativity, by providing 'positive' or 'negative' information regarding the conventional performance of peers (specifically, the number of different ways other children had purportedly found to extract rewards from the MMB). The third frame simply informed children that others' had played with the box, acting as a control. No significant effect of verbal frame (condition) upon children's performance was found; only the positive and negative normative conditions were distinguished by children's latency to first reward extraction, with those in the positive condition seen to be significantly faster than the negative. Unanticipated sex differences emerged, which appeared specifically related to male participants' enhanced approach and interaction behaviour (as evidenced in a greater number of attempts and extractions, and speed of first extraction). Nonetheless, female participants' poorer performance in this regard was not to the detriment of their innovative performance. A competency question administered at the end of testing established that the lack of significant differences was not owing to children's failure to recognise the

referenced performance of their peers. Results are discussed in light of requirements for conformity to behavioural norms, and the likely propensity for older children to override normative information in favour of individual achievement goals.

5.1 Introduction

A minority of children below the age of 8 years innovate, whether by novel invention or modification, in experimental settings. Even at this age, innovation is not universal (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; Carr, Kendal, & Flynn, 2015: Chapter 3). Whilst a number of factors may be responsible, including inability or disinclination, there is one factor that appears to be increasingly implicated in children's tendency to imitate, and consequently affects innovation: the degree to which they interpret observed behaviour as conventional or normative.

Described by Schmidt and Tomasello (2012, page 232) as the “glue of human societies”, social norms engender cooperation by encouraging behaviour in line with that of the social group. Norms prescribe correctness and appropriateness of behaviour (Rakoczy & Schmidt, 2013), acting as guides in social situations. Conventional norms, such as hand shaking at formal introductions, are distinguished from moral norms in that the former do not directly harm an individual if violated and are generally more arbitrary in nature (Turiel, 1983). Conventional norms are maintained, nevertheless, by fear of disapproval if they are violated, and a desire to conform to the ‘right’ way of doing things (Schmidt & Tomasello, 2012). These motivations evidence and sustain strong group identification, prompting conformity and, subsequently, contributing to the cultural ratchet (Schmidt, Rakoczy, & Tomasello, 2011).

Humanity's ‘norm psychology’, which enables reasoning about conventionality, develops early (Chudek & Henrich, 2011). From two years, children display early signs of adherence to normativity by preferentially copying an action performed by three individuals as opposed to an action performed by one individual

three times (Haun, Rekers, & Tomasello, 2012). One year later, children not only infer intentional actions as socially normative in the absence of explicit verbal or pedagogical cues (Schmidt, Rakoczy, & Tomasello, 2011), but they enforce normative rules upon others (Schmidt et al., 2011), protest when individuals violate established convention (Rakoczy, Brosche, Warneken, & Tomasello, 2009), and reliably use normative language in game contexts (Rakoczy, Warneken, & Tomasello, 2008). At four years, children are attuned to the behaviour and opinions of peers, such that they overlook obvious inaccuracies of their peers and align their own judgements with that of a group consensus (Haun & Tomasello, 2011). This echoes the behaviour of adults in Asch's (1956) classic social psychology experiment (though see Wilks, Collier-Baker, & Nielsen, 2015, for an important proficiency caveat to this finding). These effects are not confined to the action domain. Children acquire, from a similarly early age, an understanding of the conventional nature of artifact function (Casler & Kelemen, 2005; Casler, Terziyan, & Greene, 2009), demonstrated by protests when artifacts are used in ways contrary to their 'design'. Believing that there are normatively 'right' ways to use objects induces functional fixedness (Duncker, 1945; German & Defeyter, 2000): a phenomenon characterised by difficulty or inability to look beyond an object's conventional function and formulate novel alternative ways of using it. Indeed, functional fixedness is seen to be enhanced, along with imitation fidelity, when behavioural conventionality is primed (Clegg & Legare, 2015). Inferring conventionality of behaviour thus serves to heighten expectations for conformity to it (Legare, Wen, Herrmann, & Whitehouse, 2015), limiting potential innovation.

Though children's understanding and use of social norms becomes increasingly flexible throughout childhood (e.g., greater appreciation of their

context-specificity: Conry-Murray & Turiel, 2012; Köymen, Lieven, Engemann, Rakoczy, Warneken, & Tomasello, 2014), one domain in which perceived normativity appears to exert a particularly strong and sustained influence is that of action imitation. So called ‘over-imitation’ (Lyons, Young, & Keil, 2007), the reproduction of causally irrelevant actions, has received extensive empirical support. Various explanations have been offered for its occurrence (see Keupp, Behne, & Rakoczy, 2013, for a recent overview), including normativity. This theory supposes that children copy irrelevant actions not because they are considered causally important, but rather because they are deemed conventionally necessary (Kenward, Karlsson, & Persson, 2011; Keupp et al., 2013). Unlike other explanations for over-imitation (such as affiliation; Over & Carpenter, 2013), the normative account successfully predicts greater imitative flexibility outside the context in which the initial demonstration of irrelevant actions occurred (Keupp, Behne, Zachow, Kasbohm, & Rakoczy, 2015).

Conventionality is not only communicated by multiple individuals performing the same actions (i.e., synchronicity), but by the verbal frame that precedes behavioural demonstrations. Indeed, normative language is one of the main channels through which social norms are communicated (Rakoczy & Schmidt, 2013). Presenting an action sequence as a social convention has been achieved by stating that an actor “always does it this way” (Herrmann, Legare, Harris, & Whitehouse, 2013). This convention-oriented frame is contrasted with an outcome-oriented frame that emphasises the instrumental goal of an action sequence. The former increases children’s imitative fidelity (Herrmann et al., 2013). In corroboration, Legare et al. (2015) report that children imitate with highest fidelity when a conventional, rather than instrumental, verbal frame prefaces a novel action

sequence (see also Clegg & Legare, 2015, who report the same results with a non-instrumental, necklace-making, task). Legare et al. (2015) additionally examined children's innovative behaviour by manipulating the start- and end-states of a causally opaque action sequence. When the start- and end-states were equivalent this served to prime a conventional goal, and, when different, an instrumental goal. Observations of innovation (novel modifications of observed behaviour and/or novel behaviour not previously observed) were lower in the conventional than instrumental condition.

It is evident that cues to conventionality, whether behavioural or verbal, serve to promote imitation and reduce innovation. This is of great importance, both in terms of aiding understanding of children's difficulties with (or resistance to) innovation and in formulating interventions to facilitate the innovation process. In a previous study (Carr et al., 2015), we investigated children's imitative and innovative behaviour following social demonstrations with a novel puzzle box (the Multiple-Methods Box, MMB). Despite stating an explicit instrumental goal ("see if you can get the egg [containing a reward] out of the box"), instances of innovation (involving the discovery of a novel, and more reliable, exit to that observed) were very rare compared with imitation. Notably, several children remarked, after demonstrations, "So that's how you play the game". Consistent with Schmidt et al. (2011), inferring the social conventionality of actions can thus appear to occur even in the absence of any cues towards it (other than the repetition of a social method by a single individual). Building on our work and that of Legare et al. (2015), we examine the effect of language on children's innovative behaviour, asking: if perceived normativity typically acts to promote action imitation (by encouraging conformity), and conventional and instrumental language is able to reliably cue

specific behavioural outcomes, can verbally framing *innovation* as the normative behaviour foster its occurrence?

In order to allow for the production of a range of novel behaviours, we employed our MMB task (Carr et al., 2015); not only can the accompanying tools and box access points be used in different combinations, but there are four capsule/egg (reward) exits. Given our previous observation of children's infrequent innovation following social demonstrations, we opted to examine behaviour when children were simply presented with the box. Furthermore, to maximise appearances of novel behaviour, we selected an older sample of children (8-9 years, as seen in Beck et al., 2011; Carr et al., 2015) compared with that of Herrmann et al. (2013; 3-6-year-olds) and Legare et al. (2015; 4-6-year-olds).

We created three groups differing only in the verbal frame that preceded presentation of the MMB, to test the hypothesis that conventional language can be used to cue innovative behaviour in a similar manner to imitative behaviour. In a 'positive' normative condition, children were provided with peer-performance information that emphasised others' success in finding lots of ways (innovations) to retrieve the reward. The 'negative' normative condition conversely emphasised others' lack of success in finding lots of ways (innovations). The control condition provided no peer-performance information, simply that other children had played with the box. We investigated whether children interpreted the referenced performance of their peers as the conventional task response, and thus opted to 'conform'¹ or act in accordance with the group's established behaviour (i.e., discovering multiple ways of retrieving the reward in the positive condition, but only

¹ We note that while our study is asking whether children 'conform' to a stated behavioural norm, we are not examining conformity in the traditional sense. This is principally owing to our alluding to the behaviour (that is most frequent in others) rather than children physically observing it.

one way in the negative condition). However, it may be that children, particularly at an older age, possess more individualistic motives to pursue their own varied attempts at the task. We were also interested in whether children's conceptions of task difficulty and competence varied according to the verbal frame they received, and thus incorporated a number of questions at the end of testing. Though sex differences in children's imitation and normative behaviour have not been reported, they have been documented with regard to perceptions (self-evaluations) of ability and competence in certain domains (e.g., Cole, Martin, Peeke, Seroczynski, & Fier, 1999; Ehrlinger & Dunning, 2003; Goetz, Bieg, Lüdtke, Pekrun, & Hall, 2013; von Stumm, Chamorro-Premuzic, & Furnham, 2009). Sex was therefore examined as a component of perceived difficulty and competence.

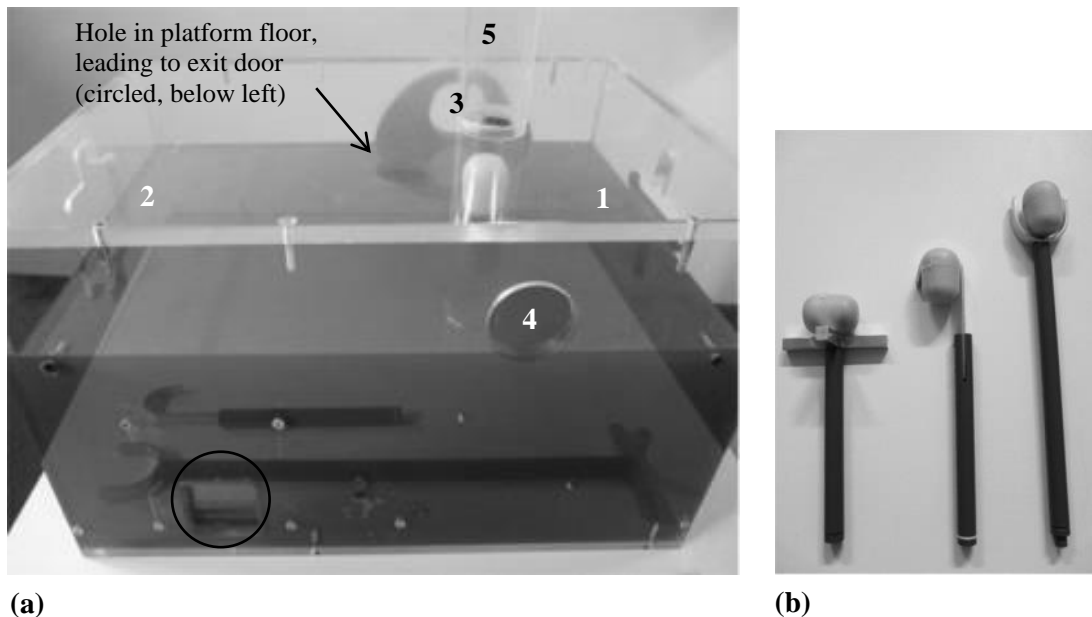
5.2 Method

5.2.1 Participants

Eighty-four children from two primary schools in the North East of England participated. Children were aged between 8 and 9 years (37 males, $M = 8$ years 11 months (8;11), range 8;0-9;8). There were no significant differences in sex [$\chi^2(2) = 0.13$, $p = .94$] or age [Kruskal-Wallis $H(2) = .99$, $p = .61$] distribution across the three conditions, and no significant differences between 8-year-olds and 9-year-olds in any of the outcome variables.

5.2.2 Materials

A puzzle box offering multiple innovation opportunities, the ‘Multiple-Methods Box’ (MMB, see Figure 5.1), was used. The MMB contains two levels separated by a platform. The upper transparent level features: an entry chute for the reward (a capsule containing a sticker which was inserted by the experimenter); four entrances, one of which required the rotation of a dial for access and three of which could also function as reward extraction points; and a small circular hole in the platform floor. If the capsule fell through this hole, it dropped to a lower opaque level of the box, via a concealed slope, to rest behind a blue exit door which could be opened to retrieve it. Three tools were available: a fork, a hook, and a sweep tool (Figure 5.1b). The fork and sweep tool could be joined and used in combination to extract the reward across a longer distance than the other single tools. Notably, not all tools fitted into all access points or were long enough to manipulate the capsule to all exit holes thus limiting their random application.



(a) **(b)**
Figure 5.1. The Multiple-Methods Box (MMB) and associated tools. (a) Access points labelled 1-5: (1) ‘Small T’, small inverted T-shape, (2) ‘End’, large inverted T-shape, opposite ‘Small T’, (3) ‘Dial’, circular hole, revealed by aligning the circle of a dial with a circle in the side of the box, (4) ‘Dial Opposite’, and (5) ‘Entry Chute’, a circular hole into which the reward was dropped. (b) Three tools were available, from right to left: fork, hook and sweep. The position of the capsule in relation to each tool demonstrates the main method of manoeuvre. The fork and sweep tool could be joined and used in combination to extract the reward, with the extra length affording extraction across the full length of the MMB, and can be seen in the reflection at the base of the box (a).

5.2.3 Design & Procedure

Children were age-ranked prior to their random allocation to one of three conditions, to ensure an even distribution of ages. These conditions differed in the verbal frame that preceded children’s attempts with the task. First, however, the experimenter presented the MMB and initiated a short warm-up phase designed to

familiarise the child with its features. This phase consisted of pointing out the access points (“holes”, given they could also serve as exits) around the box, as well as the tools positioned alongside. As in Carr et al. (2015), the box was proclaimed as belonging to a friend: “This is actually my friend’s box, and my friend told me that when this egg [the capsule] goes into the box you have to try and get it out. Inside this egg is a sticker. If you get it out of the box, we can start a sticker pile for you and we’ll see how many you can get.” Whilst this reference aimed to reduce assumed experimenter expertise and model-based biases in our previous study, with no provision of social demonstrations in the current study this was less essential. However, it may nonetheless have served to reduce any inhibition arising from otherwise perceived experimenter ownership of the apparatus/materials (Sheridan, Konopasky, Kirkwood, & Defeyter, in press).

The verbal frames of two of the three conditions were designed to provide children with information about the supposed performance of their peers. Children in the ‘positive’ experimental condition ($N = 30$) were informed that, “Lots of children have had a go with the box. Everyone who has a go has found lots of different ways to get the egg out.” The verbal frame for the ‘negative’ experimental condition ($N = 28$) similarly indicated that “Lots of children have had a go with the box”, but this time that “Everyone who has a go has only found one way to get the egg out.” Children in the third condition, the control condition ($N = 26$), were simply told: “Lots of children have had a go with the box. Let’s see how you do.”

Following the critical verbal frame, children were instructed to begin their attempts with the task. Neutral prompts were provided following each attempt (“Have another go”), except on the fourth trial when participants were reminded: “You can try anything you like.” Rather than encouraging children to explore, we

wished to observe their natural response to the task. Participants were given a maximum of eight attempt trials, over a period of five minutes; if the eight trials were not completed within this time, testing ceased. To limit continued unproductive behaviour, tool insertions were capped for children at five per attempt and a new attempt signified by the re-baiting of the box. Thus the MMB was re-baited at the end of five successive and unsuccessful tool insertions, or after each successful extraction. Upon completion of the task, children were asked their thoughts when initially informed about the performance of other children: “When I told you that... [repetition of specific verbal frame], what did that make you think?” If participants did not provide an answer, they were prompted: “Did you think it was going to be easy or hard?” and “Did you think you would find lots of ways to get the egg out or you wouldn’t find lots of ways?” The order of the options was counterbalanced between participants. These questions were asked in order to gain a greater insight into how children responded to the framing of the task (e.g., whether the ‘performance’ of peers was deemed the conventional or normative response; whether the positive condition decreased perceived difficulty of the task and the negative condition increased it, impacting upon the number of innovations produced; and whether the negative condition prompted a competitive effect).

At the end of testing all children were praised for their performance and rewarded with a sticker irrespective of their level of success (small stickers collected during testing were traded for one larger and more desirable sticker).

5.2.4 Coding & Inter-Rater Reliability

Participants' overall performance was scored on the following variables: number of attempts (maximum = 8); number of reward extractions (capsules removed from the MMB; max. = 8); number of tools used (max. = 6; fork, hook, sweep, combined fork, combined sweep, tool end), access points used (max. = 5; small T, end, dial, dial opposite, entry chute), and exits used (max. = 4; end, dial, dial opposite, door); number of methods (specific combinations of tool, access point, and exit); number of *successful* exits used and number of *successful* methods produced (denoting the fact that not all participants who maneuvered the capsule to the exit door discovered how to open it and hence achieve extraction); number of method repetitions; and latency to first extraction (timed from end of experimenter instructions, with a ceiling latency of 300s given if no extraction was achieved throughout attempts). With tools and access points, we additionally made a more nuanced distinction between those that were *discovered* (used as part of the five tool insertions per attempt but not used together with an exit to bring about an outcome, i.e., were abandoned prior to a different tool/access point being selected) and those that were *used as part of a method* (used to manoeuvre the capsule to an exit and effect an outcome). Participants' responses to experimenter questions were coded according to the reported perceived difficulty of the task (easy, hard, middle) before they had attempted the task, and perceived competency at finding ways to retrieve the capsule from the box (again, perceptions prior to attempts).

The experimenter, KC, coded 100% of the sample from video tape. An independent observer, blind to the hypotheses of the study, coded 20% of the

sample. All intra-class correlation values were 0.88 or above, showing an excellent level of inter-rater reliability (Cicchetti, 1994).

5.2.5 Statistical Methods

As the data were not normally distributed, non-parametric tests were used. Where multiple tests were conducted with the same outcome variable, a Bonferroni correction was applied (by dividing the critical significance level of .05 by the total number of tests conducted) to avoid inflating the Type I error rate. Corrections were made for tests within, rather than across, variables given that we were interested in the nuances of children's behaviour (that is, how they performed in relation to a number of aspects of the MMB task). However, an additional correction was made for the three measures of 'successful' innovation that were recorded (tools used in a method, access points used in a method, and successful exits).

5.3 Results

The results are presented in three sections. First, we examine between-condition differences in children's performance on the MMB task. Second, in response to observations during testing, we explore sex differences in performance across and within conditions. Finally, we analyse children's responses concerning perceived difficulty and competence in relation to the task. All tests were two-tailed unless otherwise stated.

5.3.1 Did Children Differ in Their Task Performance Between Conditions?

Our primary question concerned whether verbal framing differentially influenced participants' performance, and the extent to which they innovated, on the MMB task. As the verbal frames were explicit in their emphasis upon capsule removal (ways to get the egg *out* of the box), there was a particular focus upon the number of exits used by participants. However, we recognised that children in the positive and negative experimental conditions may have interpreted 'ways' differently (i.e., using the same exit but a different tool and/or access point may be considered a different 'way') and so we also compared the number of tools and access points used between groups (see Table 5.1). A table containing definitions of variables is first provided as a reminder of their conceptualisation.

Table 5.1

Variables Subject to Statistical Analysis

Variable	Description
Attempts	Total number of attempts made (max. 8), with each attempt comprising up to five tool insertions
Extractions	Total number of successful reward extractions, irrespective of extraction method (max. 8)
Tools/Access Points Discovered	Total number of tools/access points attempted, but not used in successful combination with an exit to bring about an outcome (were abandoned prior to an alternative selection)
Tools/Access Points Used in a Method	Total number of tools/access points used in successful combination with an exit to bring about an outcome (reward extraction, or capsule to exit door)
Exits	Total number of exits used, including the exit door irrespective of whether its opening mechanism was discovered
Successful Exits	Total number of exits used that led to successful reward extraction (excluding capsule to exit door if opening mechanism was not discovered)
Methods	Total number of methods (combinations of tool, access and exit) enacted, irrespective of success
Successful Methods	Total number of methods (combinations of tool, access and exit) enacted that led to successful reward extraction(s)
Method Repetitions	Total number of repetitions of specific combinations of tool, access point and exit
Extraction Latency	Time taken to first reward extraction, from end of experimenter instructions (max. 300s)

Table 5.2

Descriptive Statistics of Outcome Variables Across Conditions, Together With the Test Statistics and Probability Values Generated by Group Comparisons With the Kruskal-Wallis Test

	Experimental Condition							
	Positive		Negative		Control		Kruskal-Wallis	
	Mean (SD)	Mdn	Mean (SD)	Mdn	Mean (SD)	Mdn	<i>H</i>	<i>p</i>
Attempts	5.90 (1.63)	6	5.73 (1.91)	5.5	6.04 (1.72)	6	0.18	.91
Extractions	5.21 (1.80)	5	4.92 (2.23)	5	5.00 (2.18)	5	0.28	.87
Tools (D)	2.66 (1.08)	3	2.42 (0.99)	2.5	2.56 (0.87)	3	1.55	.46
Tools (M)	2.07 (0.91)	2	1.68 (0.77)	1.5	1.88 (0.91)	2	3.24	.20
Access (D)	2.97 (1.05)	3	3.12 (0.95)	3	2.96 (0.73)	3	0.94	.63
Access (M)	2.53 (1.01)	3	2.39 (0.99)	2	2.31 (0.97)	2	0.92	.63
Exits	2.66 (1.01)	3	2.54 (1.21)	2.5	2.32 (0.95)	2	1.50	.47
<i>Successful</i>	2.28 (1.00)	2	2.19 (1.23)	2	1.92 (0.81)	2	0.98	.61
Methods	3.76 (1.46)	4	3.38 (1.60)	4	3.36 (1.22)	3	1.60	.45
<i>Successful</i>	3.17 (1.54)	3	2.85 (1.74)	2	2.72 (1.21)	3	1.46	.48
Method Reps	2.03 (1.94)	1.5	2.23 (2.37)	1.5	2.52 (1.81)	2	1.52	.47
Extraction	78.03	46	119.32	100.5	109.50	78.5	5.62	.06
Latency	(72.59)		(82.20)		(86.90)			

Note. (D) = discovered, (M) = used as part of a reward extraction method, Reps = repetitions

As can be seen in Table 5.2, only one marginal group difference (extraction latency) was found. Investigating this result further, participants in the positive condition ($Mdn = 46$, $SD = 72.59$) were significantly faster at achieving their first extraction than participants in the negative condition ($Mdn = 100.5$, $SD = 82.20$; Mann-Whitney $U = 264$, $z = -2.43$, $p = .015$, corrected $p = .017$). There were no significant differences between the control and the positive- ($U = 305$, $z = -1.40$, $p = .16$), or negative ($U = 328.5$, $z = -0.62$, $p = .54$) conditions.

Participants varied widely in how many attempts they enacted (see Table 5.3), with a mean number of 5.77 attempts found across conditions despite allowing for eight. Though there were no significant differences between conditions in the number of attempts made ($H(2) = .18$, $p = .91$), male participants made significantly more attempts ($Mdn = 6$, $SD = 1.78$) than female participants ($Mdn = 5$, $SD = 1.87$; $U = 606$, $z = -2.42$, $p = .02$). In view of the variability and sex differences found, we standardised our outcome variables by dividing each participant's scores by the number of attempts they made. Re-running the Kruskal-Wallis analyses on the standardised variables revealed no significant differences between conditions. Thus, the initial results do not appear to be an artefact of variability in the number of attempts made. However, subsequent analyses (Section 5.3.2) incorporating both raw and standardised scores are presented for completeness.

Table 5.3

Number of Attempts Made by Participants, Across Conditions

Number of Attempts	Number of Participants
1	3
2	2
3	5
4	8
5	18
6	16
7	11
8	21

5.3.2 Did Male and Female Children Differ in Their Task Performance?

Although we did not initially set out to investigate sex differences, there appeared during testing to be some consistent differences in the way in which male and female participants approached the task (specifically, in the ease with which they contacted and interacted with the apparatus). We thus opted to undertake analyses on the male and female groups across and within conditions.

Across conditions, male and female participants significantly differed in four outcome variables. Male participants not only made significantly more attempts than female participants (see Section 5.3.1), but achieved significantly more extractions (males: $Mdn = 6$, $SD = 2.29$; females: $Mdn = 5$, $SD = 2.19$; $U = 639$, $z = -2.10$, $p = .04$). However, when controlling for number of attempts, female participants produced significantly *more* methods ($Mdn = 0.75$, $SD = 0.30$) than males ($Mdn = 0.60$, $SD = 0.26$; $U = 655$, $z = -1.95$, $p = .051$). Females also enacted significantly fewer method repetitions, for raw scores (females: $Mdn = 1$, $SD = 1.98$; males: Mdn

= 2, $SD = 2.03$; $U = 582.5$, $z = -1.71$, $p = .01$) and standardised scores (females: $Mdn = 0.2$, $SD = 0.26$; males: $Mdn = 0.4$, $SD = 0.26$; $U = 606$, $z = -2.40$, $p = .02$). Male participants had greater task success (evident in reward extractions) as a function of their greater number of attempts. However, female participants required fewer attempts than males to produce novel combinations of tool, access point, and exit (methods), irrespective of the success of these combinations at bringing about reward retrieval.

To determine the extent to which these results were driven by the verbal frame participants' received, further analyses within conditions were necessary. Descriptive and test statistics are presented in Table 5.4. Whilst there was nothing to distinguish male and female participants when they believed other children "only found one way to get the egg out of the box" (negative normative condition), this was not the case for the positive normative condition and control condition. As the difference in attempt number between males and females only approached significance in the positive normative condition ($U = 67$, $z = -1.90$, $p = .06$), analyses within this condition were conducted on raw scores (thus not controlling for attempt number). Females were found to make significantly fewer extractions ($U = 64$, $z = -2.02$, $p = .047$) and method repetitions ($U = 54.5$, $z = -2.47$, $p = .02$) than males when informed that everyone "has found lots of different ways to get the egg out of the box". When simply prompted "Let's see how you do", as in the control condition, female participants again made significantly fewer extractions than males ($U = 31.5$, $z = -2.67$, $p = .01$) but also significantly fewer attempts ($U = 43.5$, $z = -2.06$, $p = .04$). This thus necessitated consideration of the standardised scores. Differences in only one standardised outcome variable were found to approach significance, with males performing more method repetitions than females ($U = 47$, $z = -1.86$, $p = .06$) in the

control condition. However, significant differences were found in latency to first extraction (standardised score not appropriate): male participants achieved their first extraction faster than female participants ($U = 31$, $z = -2.67$, $p = .01$), again in the control condition.

Table 5.4

Descriptive Statistics (Median and (SD)) of Outcome Variables For Male and Female Participants Across Conditions, Significant Effects, and Test Statistics and Probability Values Generated by Mann-Whitney U Tests

	Positive (P)		Negative (N)		Control (C)		Sig. Effects	<i>U</i>	<i>z</i>	<i>p</i>
	Male	Female	Male	Female	Male	Female				
Attempts	6.5 (1.70)	5 (1.45)	5.5 (2.27)	5.5 (2.03)	7 (1.08)	5.5 (1.91)	C Male > C Female	43.5	-2.06	.04
Extractions	6 (2.23)	4 (1.63)	5 (2.59)	5 (2.42)	6 (1.27)	3.5 (2.25)	P Male > P Female	64	-2.02	.047
							C Male > C Female	31.5	-2.67	.01
Tools (D)	2.5 (1.01) <i>0.44 (0.26)</i>	3 (1.09) <i>0.6 (0.25)</i>	2.5 (0.98) <i>0.39 (0.33)</i>	2 (1.02) <i>0.41 (0.22)</i>	3 (0.67) <i>0.38 (0.11)</i>	3 (1.02) <i>0.50 (0.40)</i>	--			
Tools (M)	2 (0.86) <i>0.31 (0.25)</i>	2 (0.93) <i>0.5 (0.24)</i>	1.5 (0.78) <i>0.39 (0.27)</i>	1.5 (0.79) <i>0.31 (0.24)</i>	2 (0.75) <i>0.25 (0.13)</i>	2 (0.92) <i>0.41 (0.25)</i>	--			
Access (D)	3.5 (1.10) <i>0.5 (0.25)</i>	3 (1.02) <i>0.67 (0.25)</i>	3.5 (1.16) <i>0.54 (0.26)</i>	3 (0.89) <i>0.60 (0.22)</i>	3 (0.83) <i>0.43 (0.16)</i>	3 (0.66) <i>0.54 (0.28)</i>	--			
Access (M)	2.5 (1.09) <i>0.46 (0.18)</i>	3 (0.96) <i>0.6 (0.22)</i>	3 (1.09) <i>0.40 (0.30)</i>	2 (0.95) <i>0.40 (0.27)</i>	2 (0.93) <i>0.38 (0.15)</i>	2 (0.83) <i>0.41 (0.24)</i>	--			
Exits	3 (1.15) <i>0.39 (0.18)</i>	3 (0.96) <i>0.54 (0.20)</i>	2.5 (1.24) <i>0.54 (0.29)</i>	2 (1.25) <i>0.46 (0.31)</i>	2 (0.92) <i>0.33 (0.17)</i>	2 (0.99) <i>0.41 (0.22)</i>	--			
S. Exits	2.5 (1.20) <i>0.38 (0.20)</i>	2 (0.96) <i>0.41 (0.19)</i>	1.5 (1.54) <i>0.29 (0.32)</i>	2 (1.18) <i>0.40 (0.27)</i>	2 (0.75) <i>0.33 (0.14)</i>	1.5 (0.83) <i>0.27 (0.19)</i>	--			
Methods	3 (1.51) <i>0.61 (0.24)</i>	4 (1.45) <i>0.82 (0.26)</i>	3.5 (1.31) <i>0.59 (0.32)</i>	3 (1.86) <i>0.80 (0.34)</i>	3 (1.36) <i>0.50 (0.24)</i>	3 (1.15) <i>0.65 (0.23)</i>	--			
S. Methods	3 (1.75) <i>0.46 (0.29)</i>	3 (1.54) <i>0.71 (0.26)</i>	2 (1.76) <i>0.35 (0.36)</i>	2 (1.88) <i>0.40 (0.33)</i>	3 (1.18) <i>0.43 (0.20)</i>	2 (1.22) <i>0.46 (0.26)</i>	--			
Method Reps	2.5 (1.93) <i>0.38 (0.23)</i>	1 (1.66) <i>0.18 (0.22)</i>	2 (2.39) <i>0.34 (0.32)</i>	1 (2.53) <i>0.20 (0.33)</i>	3 (1.85) <i>0.50 (0.23)</i>	2 (1.59) <i>0.33 (0.21)</i>	P Male > P Female	54.5	-2.47	.02
Ext. Latency	46 (76.26)	55 (71.57)	113 (96.62)	72.5(65.33)	43 (51.66)	149.5(83.50)	C Male > C Female	31	-2.67	.01

Note. (D) = discovered, (M) = used as part of a reward extraction method, S = successful (with regard to reward extraction), Reps = repetitions, Ext. = extraction. Descriptive statistics reported in italics are those for the standardised scores. The test statistics and probability values are only shown for significant effects due to space limitations.

As it was unclear whether the positive and control conditions were eliciting different responses from participants or affecting performance in the same way, condition and sex were entered as independent variables into a two-way ANOVA, and the outcome variables identified above as significantly distinguishing the male and female groups (number of attempts, number of extractions, method repetitions (raw and standardised), and extraction latency) entered separately as dependent variables. We were unable to conduct an equivalent non-parametric test capable of incorporating both condition and sex. Thus, whilst analyses of variance are relatively robust to violations of normality (Field, 2009), caution is required in the interpretation of these results given that our data are not normally distributed.

A significant main effect of sex was found for all outcome variables excepting extraction latency ($p = .40$). The main effect of condition was non-significant in all cases ($p > .05$), and a significant interaction between sex and condition found for the number of extractions variable ($F(2,78) = 4.59, p = .013$) and latency to first extraction ($F(2,78) = 4.94, p = .01$). A subsequent simple effects analysis revealed no significant difference in the number of extractions made by males and females in the positive condition ($F(1,78) = 2.61, p = .11$) or negative condition ($F(1,78) = 1.47, p = .23$), but a significantly higher number of extractions for males in the control condition relative to females (Figure 5.2; $F(1,78) = 8.77, p =$

.004). The control condition, therefore, appeared to exert the strongest (detrimental) effect on female participants' success at extracting rewards from the MMB. This pattern of results was replicated when examining latency to first extraction: no significant difference between males and females in the positive ($F(1,78) = 0.06, p = .81$) or negative condition ($F(1,78) = 2.65, p = .11$), but a significantly shorter latency to first extraction for males in the control condition relative to females (Figure 5.3; $F(1,78) = 7.74, p = .01$). Significant differences in the other variables (number of attempts and method repetitions) appeared to capture sex differences that were not specific to participant condition.

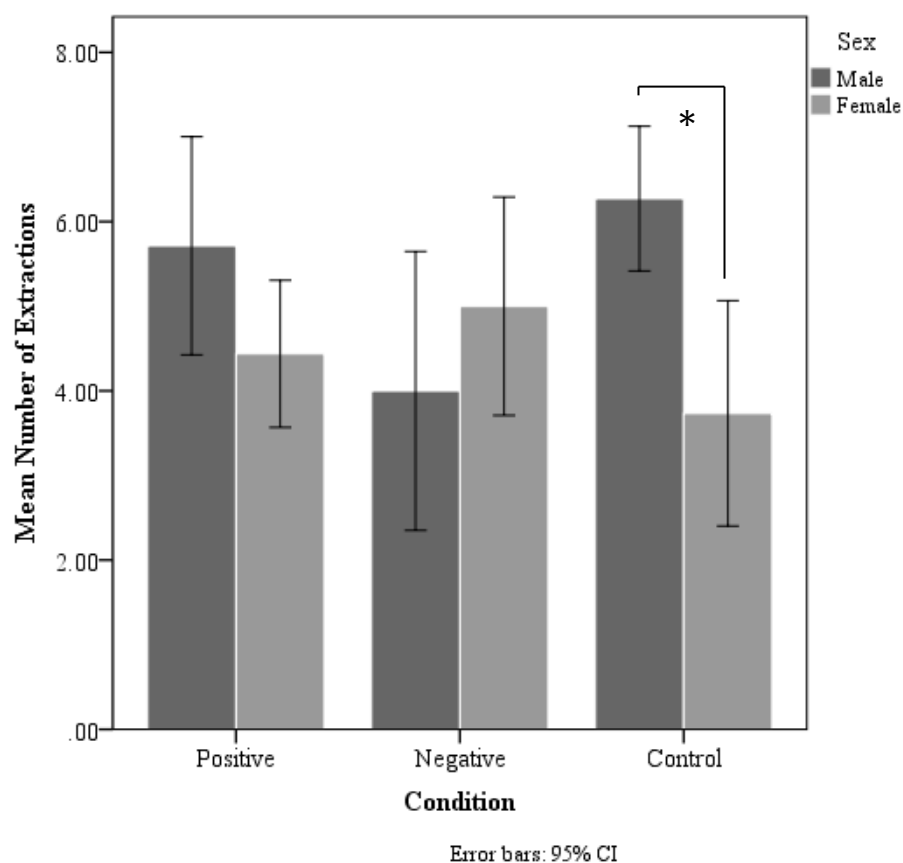


Figure 5.2. Mean number of extractions achieved by male and female participants across conditions. Means are presented owing to the parametric analysis undertaken.

* $p < .01$

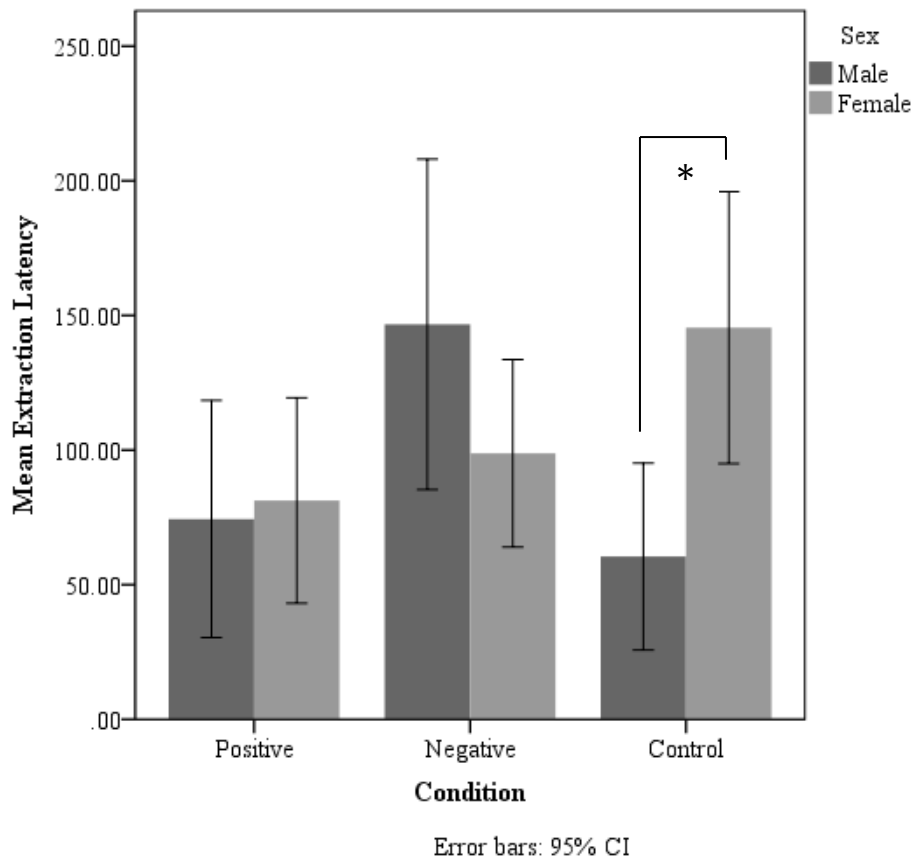


Figure 5.3. Mean latency to first extraction achieved by male and female participants across conditions. Means are presented owing to the parametric analysis undertaken.
* $p < .05$

5.3.3 Did Children's Perceptions of the Task Qualitatively Differ in Line With the Verbal Frame They Had Received?

At the end of testing, the majority of children, across conditions, expressed that they initially believed the task would be difficult as opposed to easy (56 'hard' responses versus 17 'easy' and 7 'middle'). Fisher's exact tests revealed no significant differences in these categorised responses between positive, negative and control conditions ($N = 80$, $p = .83$) or between male and female participants ($N = 80$, $p = .21$). However, it is possible that any variation in perceived difficulty arising

as a result of the verbal frame (the task may have been interpreted as easy when told others “find lots of different ways”, but difficult when they “only find one way”) was concealed by a general perception for children that any task, that has not been attempted before, will be challenging.

In addition to difficulty, children were asked to reflect upon how many ways they initially believed they would find to get the egg out of the box (‘lots of ways’ versus ‘not many ways’). Only unambiguous answers were coded; that is, those that clearly expressed a *personal* belief about the number of ways that could be found. On this basis, the answers of 22 participants were excluded. Of the remaining 62 participants, 33 expressed the belief that they would find lots of ways, compared with 29 who believed they would *not* find many ways. A roughly equal number of males and females produced each response. To determine whether children’s beliefs were congruent with the normative verbal frame they received, it was necessary to exclude control participants. Almost 75% of participant responses (36 of 49) across the positive and negative conditions were in line with the verbal frame administered. In other words, the majority of participants appeared to use the performance of their peers (as communicated by the experimenter) as a guide when judging their own competency to complete the task. When the main analyses (Section 5.3.1) were re-run including only the 36 congruent-participants ($N = 17$, positive condition; $N = 19$, negative condition), no significant differences in any outcome variables were discerned.

5.4 Discussion

Contrary to our hypothesis, the normative verbal frames, intended to convey behavioural conventionality and cue conformity, did not serve to differentially increase or decrease displays of innovative behaviour. Children in the positive normative condition were no more likely than children in the negative normative condition to discover and use novel tools, access points and exits of the MMB, or produce a greater variety of methods to retrieve the reward. The normative frame which emphasised others' success (to find "lots of different ways to get the egg out of the box") did, however, result in faster first reward extractions than the normative frame which emphasised others' low level of success ("only found one way to get the egg out of the box"). Unanticipated sex differences emerged, which appeared related to children's approach and interaction behaviour. Specifically, across conditions, male participants succeeded in making significantly more attempts and achieving more reward extractions than female participants. Female participants' reduced number of attempts, however, was not at the detriment of the discovery of novel methods (of which they produced significantly more than males). Sex differences were largely independent of experimental condition, with two exceptions (number of reward extractions and latency to first extraction). Qualitative data, concerning participants' perceptions of task competence, indicated that the lack of significant differences between normative conditions was not owing to children's failure to recognise the referenced performance of their peers.

The general absence of differentiation between the positive and negative normative conditions, and indeed the normative and non-normative (control) conditions, may be interpreted in a number of ways. First, it could suggest that

children do not infer behavioural conventionality from verbally-communicated information, such as task instructions. Whilst convention-oriented verbal frames have previously been seen to increase children's imitative fidelity (Herrmann et al., 2013; Legare et al., 2015), such frames have critically been followed by behavioural demonstrations. In the current study, the verbal frames prefaced children's own attempts with the task; no demonstrations were provided. Behavioural demonstrations may heighten the influence of task framing by corroborating the verbal information. Certainly, normative language is one of the primary means through which social norms are communicated (Rakoczy & Schmidt, 2013); yet, references to normative behaviour may not be as powerful a cue to conventionality and, hence, as powerful a behavioural prime, as references *and* observations of it (or even just observations in the case of intentional action; Schmidt et al., 2011). In everyday life, we receive both physical and verbal evidence of the existence of social norms, in line with established social convention, and evidence of individuals verbally reproaching those who do not adhere.

We cannot say with certainty whether children in the current study interpreted the verbal frames as a cue to others' performance, rather than a cue to social convention (the implications of which are later discussed). The majority of participants who provided unambiguous personal competency beliefs appeared to use the reported performance of their peers as a guide: believing they would find lots of ways when informed that others did, and similarly that they would not find many ways when others did not. Nevertheless, peer-performance information was not seen to help or hinder actual task performance, only the speed with which participants attained their first extraction - the advantage being in favour of participants in the positive normative condition. Given it was initial extraction latency and not

innovative performance that was affected, we may reasonably speculate that this was an induced effect of confidence: believing that ‘if others can do well, then so then can I’. Confidence in one’s own proficiency not only promotes personal information use but decreases reliance on social information (Morgan, Rendell, Ehn, Hoppitt, & Laland, 2012), demonstrating its potentially powerful effect upon behaviour. Children may have also acquired greater confidence in the positive normative condition as a result of anticipated ease with the task; if children are more likely to imitate an adult’s means of achieving a goal following a difficult prior experience themselves (Williamson, Meltzoff, & Markman, 2008), it follows that children in the present study who believed peers had an easy experience (arguably deduced from their discovery of ‘lots of ways’) might have possessed greater confidence in their own personal abilities as demonstrated in their significantly faster exploration.

A further difference between our own study and that of prior studies (Herrmann et al., 2013; Legare et al., 2015) was the older sample of children selected. This was in order to increase the theoretical range of novel behaviours that would be produced, in view of findings that children become more reliably innovative in later childhood (Beck et al., 2011; Carr et al., 2015). However, the enhanced cognitive capacity and/or flexibility of older children (e.g., to consider and produce behavioural alternatives) inevitably also extends to other abilities. Thus, a second interpretation for our findings is that the 8- to 9-year-olds in the current study did, in fact, recognise the communicated behavioural norm but, owing to greater normative flexibility and lack of pressure to ‘conform’, did not perceive the need or possess the desire to alter their behaviour in line with that of peers. Compared with 3- to 4-year-olds, older children are more selective regarding the contexts in which norms apply (Köymen et al., 2014) and more flexible in views regarding their rules

and enforcement (Conry-Murray & Turiel, 2012). This ability to comprehend the context-specificity and limits of norms is fundamental to reliable assessments of their violation, but also to the importance and necessity of their adherence. It is also worth acknowledging that the form taken by the convention in the present study may have additionally served to reduce ‘conformity’ to it. That is, rather than normativity being associated with a specific task solution, it was associated more generally with the number of solutions possible. The latter is arguably easier to override given it does not directly attest to the specific way a behaviour is normatively enacted (as in Clegg & Legare, 2015, Herrmann et al., 2013 and Legare et al., 2015).

Conventional norms are in part maintained by a fear of disapproval if they are violated (Schmidt & Tomasello, 2012; Turiel, 1983). Indeed, fear of ostracism and social exclusion, two possible outcomes associated with breaching established social conventions of one’s social group, drives high fidelity *affiliative* imitation (Over & Carpenter, 2009; Watson-Jones, Legare, Whitehouse, & Clegg, 2014). In the current study the referenced peers were not present to witness any violations thereby reducing the possibility of disapproval, ostracism or sanctions (although the experimenter was present, there was no indication or mention of subsequent normative evaluation; in other words, that comparisons of performance would be undertaken). Moreover, unlike in typical conformity studies, the participating children did not physically observe the majority behaviour (i.e., peers being more or less successful at solving the task). This would theoretically have considerably increased the likelihood of its adoption, in line with a ‘copy the majority’ learning strategy (Laland, 2004). It is also important to consider that conformity decreases with age in childhood (in unambiguous tasks; Walker & Andrade, 1996), is reduced with incentives for accuracy (such as stickers to be gained with each successful

reward extraction in the current study; dependent on task difficulty: Baron, Vandello, & Brunsman, 1996), reduced when a private rather than public response is given (Asch, 1956; Haun & Tomasello, 2011), and (at least in preschoolers) superseded by a preference for copying a single proficient individual in the event that an observed group is unsuccessful at achieving a goal (Wilks et al., 2015). The disparities with typical conformity studies, and the mediating factors identified, may have contributed to a perception for participants that the behavioural norms in the present study were not particularly pertinent in terms of their adherence.

Our third and final account for the absence of a normative effect, and the one we believe also helps best explain the observed sex differences, proposes that children's own motivations to solve the task outweighed any possible effects of inferred behavioural conventionality. Without the provision of social demonstrations, children were confronted with an individual learning situation involving a novel and challenging problem-solving task, and one in which it was possible to gain mastery and prove ability. Achievement goals can be "[d]efined normatively (demonstrating competence relative to others) or self-referentially (developing competence or skills)" (Harackiewicz & Elliot, 1993, p.904), and they arguably had a large role to play in the present study. Whilst it is not possible to know for certain which achievement goals our participants possessed, we can make some speculations based on the findings observed.

Social comparison information, that which allows individuals to generate an understanding of, and self-evaluate, their relative status in relation to others (Klein, 1997), was present in our two normative conditions. By appearing to align competency beliefs with peer-performance information, participants here evidenced such social comparison. However, as children's task performance was not affected,

the peer-performance/social comparison information may have simply set a performance benchmark; one which, contrary to our hypothesis for the negative normative condition, was motivational as opposed to limiting. Interestingly, this is still a normative process (specifically of evaluation) but behaving normatively is not the intended goal. Rather than conform to the supposed low-level performance of peers, participants who received the negative normative frame may have acquired a competitive performance goal which motivated them to outperform other children: 'I can do better than that and will try to find lots of ways'. It is equally possible that participants in the negative normative condition, and indeed the positive and control conditions, held mastery goals. Motivation for mastery denotes the "desire to solve cognitively challenging problems for the gratification inherent in discovering the solution" (Harter, 1975, p.370). Situations in which mastery goals are pursued, such as many tasks in school, are associated with a variety of positive learning and achievement outcomes, as well as increased intrinsic motivation (e.g., Bergin, 1995; Butler, 2006; DeCaro, DeCaro, & Rittle-Johnson, 2015; Spinath & Steinmayr, 2012). Here, the performance of others could have been acknowledged (and, again, used to establish a benchmark) but deemed of lesser importance than that which could be individually learned and achieved.

Known interactions between achievement goals and an individual's own perception of ability help shed light onto the observed sex differences. When self-concepts are positive and perceived ability is high, there is an increased chance of demonstrating high competence or avoiding demonstrating low competence (Spinath & Steinmayr, 2012) - whether motivated by individual mastery or by the performance of others (Nicholls, 1989). Those with lower perceived ability, however, are more likely to experience performance deficits in response to ego-

involved (competitive) performance goals (Nicholls, 1989). Critically, there is a long history of research that suggests females fare worse than males when it comes to accurate estimates of their abilities, and indeed consistently *underestimate* them (both children and adults; e.g., Cole et al., 1999; Ehrlinger & Dunning, 2003; Goetz et al., 2013; von Stumm et al., 2009). Though we did not find sex differences in response to our question of perceived competence, asking this question *after* participant attempts, when personal experience could have potentially altered initial beliefs, may have been responsible.

In the current study, underestimations of ability, and the lowered confidence that necessarily accompanies these evaluations, may have adversely affected female participants' approach and interaction behaviour. Across conditions, females enacted fewer attempts and achieved fewer reward extractions than males. However, their capacity to discover different ways (to get the egg/capsule out of the box) was not hindered. Indeed, when attempt number was controlled for, females enacted more methods (specific combinations of tool, access point and exit) than males.

Within-condition analyses suggested the positive and control conditions were distinct from the negative condition in eliciting the sex differences. There was nothing to distinguish males and females when negative normative information was provided. In this condition, compared with the positive condition, there is a low chance of performing worse than peers, thereby reducing performance pressure. Thus, if a performance goal was elicited, and females did indeed possess lower estimates of their ability than males, negative assessments may have been countered by a lowered expectation to perform well and possibly increased confidence to succeed in turn. Male participants' achievement of more extractions is perhaps also reflective of their greater competitive orientation (as seen, for example, in their play

behaviour: Maccoby & Jacklin, 1987; see also Niederle & Versterlund, 2011), likely making performance goals and their achievement especially salient for these individuals. A resultant emphasis on speed, as suggested by the greater number of attempts and extractions made by males, could account for their greater number of method repetitions.

Performance pressure was arguably considerably heightened in the positive condition (when performance could potentially be deemed worse than that of peers) and, to a lesser degree, the control condition, where the direction of the social comparison is unknown. In the absence of private confidence, of plausibly greater concern for female participants, pressure can harm performance (Baumeister, Hamilton, & Tice, 1985). The control condition appeared specifically responsible for the findings of fewer extractions and longer latency to first reward extraction in females than males. It is unknown why this may have been the case, particularly given that performance goals would arguably have played less of a role in this condition. Given that actual innovative ability (the capacity to discover and use novel tools, access points and exits of the MMB, and produce novel methods) was not affected by the sex of participants, the findings may rather reflect sex differences in approach and continued interaction behaviour – perhaps somewhat akin to neophobia (fear of novelty).

As sex differences have not been found in tool-use studies elsewhere, we must be cautious with interpretations and generalisations of our findings. Though interesting, and partially consistent with the operation of performance goals, they require replication. Nevertheless, emphasis of their potential impact is still warranted. Female participants demonstrated what may be regarded as a more conservative or less confident task approach, evidenced by their achievement of

fewer attempts/extractions and slower speed in the initial extraction (control condition only). Whilst this did not result in poorer performance when it came to innovating (discovering new tools, access points, exits and methods on the MMB task), this is not to say that such a difference in approach could not have a detrimental impact upon innovation in another situation (involving a different task), context (such as a social group) or point in time. Ehrlinger and Dunning (2003) provide, as one example, a compelling and worrying illustration of the impact of women's negative self-views upon science participation and consequently their likelihood of pursuing scientific careers. Crucially, this is motivated not by actual performance ability but by pessimistic perceptions of abilities. The educational implications are thus profound.

Whilst we have advanced three primary hypotheses as to why the verbal frames may not have had the expected impact on children's displays of innovative behaviour with the MMB task, a further possibility remains. It may be that the experimental manipulation, the verbal frames themselves, were simply too weak or subtle to generate a normative effect. Verbally-communicated normative information may well prompt individuals to increase their exploration and innovation, but exactly what forms the *content* of this information may be key. Future research that varies the information contained within normative frames, and how this information is conveyed, will be essential to more definitively establish the role of normativity in innovation.

We have documented in the current study the apparent absence of a normative effect of verbal frames on 8- to 9-year-olds' innovative behaviour. We propose that in an individual learning situation, older children's own motivations to solve a task, whether to demonstrate superior ability to others or to gain competence

and mastery, outweigh the propensity to align behaviour with that of peers, particularly when those peers are absent. In future research, the inclusion of younger participants, the introduction of demonstrations of peer behaviour, and the documentation of perceived abilities prior to task attempts, would help isolate the factors at work in our findings.

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Chapter 6

Innovation takes time: Children's novel behaviour production is aided by increased time, and prompted opportunities to interact with and explore a tool-use task

Abstract

The current study set out to gain a more comprehensive and ecologically-valid understanding of children's exploration and innovation abilities. Following the provision of social information and acquisition of personal experience with a novel puzzle box (Multiple-Methods Box, Phase 1; Carr, Kendal, & Flynn, 2015: Chapter 3), 4- to 9-year-old children ($N = 199$) were permitted additional prompted attempts with the MMB in a second task phase. The MMB offers multiple exploration and innovation opportunities, by providing numerous tool, access point and exit action components and allowing for their various combinations. Having previously evidenced high levels of imitative fidelity and low rates of innovation (specifically directed toward the exit door of the box, which varied in its reliability), children were seen to produce a significantly greater number of tool, access point and exit innovations with increased time and opportunity to explore the box along with explicit instructions and prompts to do so. The social demonstrations observed prior to participants' first round of attempts in Phase 1 were of lesser influence in Phase 2, with the social method being enacted on fewer attempt trials. Nonetheless, the exploration of those participants who had initially observed a more efficacious social method (75% and 100% success conditions) was selectively enhanced in the case of two outcome variables. In discovering imitation to decrease with age and innovation

to increase, this study replicated the developmental trends reported in Phase 1 and supports the competence-based interpretation advanced. The results importantly indicate that experimental approaches with short timeframes in which innovation may be evidenced could underestimate children's capacity to produce novel behaviour.

6.1 Introduction

Within developmental psychology, children have received various accolades: as ‘cultural magnets’ (Flynn, 2008), sophisticated explorers (Legare, 2014), faithful yet selective social learners (Over & Carpenter, 2013), and ‘like’ scientists (Gopnik, 2012). Yet, very rarely, if ever, are children regarded as ‘innovators’. Here, we see a distinct separation between children as they are naturally observed in everyday life, as creators of complex, novel, imagined scenarios within pretend play (Nielsen, 2012) as one example, and children as they are observed in typical experimental contexts, as exemplary social learners and, by and large (at least until late childhood; e.g., Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; Carr, Kendal, & Flynn, 2015), poor tool makers and modifiers of social information (innovators). Certainly, young children seem to experience great difficulties with innovation. Their ability to innovate appears particularly hampered following social demonstrations (Carr et al., 2015; Wood, Kendal, & Flynn, 2015) and when presented with ‘ill-structured’ tool innovation problems (which lack the information required to get from a start state to an end state; Cutting, Apperly, Chappell, & Beck, 2014).

Aside from inducing explanations of developing cognitive capacity and flexibility, canalisation to existing information, and obstacles such as functional fixedness (see Carr, Kendal, & Flynn, accepted (Chapter 2), for further discussion), we may question whether part of children’s innovation difficulties lie in ‘simpler’ matters; specifically, whether existing experimental approaches and procedures provide sufficient time with new physical materials for children to generate novel ways of successfully manipulating them. In the real world, innovation with tools or other objects would not naturally be expected to occur within a set time frame - let

alone a relatively short one. Findings are beginning to emerge that suggest the context in which innovation is assessed will be a determinant of its production. For example, comparing known rates of tool innovation on the hook task in a school setting (Beck et al., 2011) with those obtained in a museum, Sheridan, Konopasky, Kirkwood, and Defeyter (in press) report a facilitatory effect of the latter environment upon children's innovation. This raises the interesting possibility that the open use of materials and availability of time and opportunity to explore can aid children's innovation difficulties.

The current study set out to achieve greater external/ecological validity by investigating whether children's innovation may be facilitated by simple experimental manipulations: extended time to interact with and explore a novel task, and repeated prompts to try out new behaviours. By testing these manipulations in an experimental phase that took place after children had gained observational and personal experience of a socially demonstrated method that varied in its efficacy (success at extracting a reward from a novel puzzle box; Carr et al., 2015), a second study objective could be achieved. This second objective involved examining the extent to which prior social information, seen to promote imitative fidelity (Carr et al., 2015), continued to influence the range of novel task behaviours that children attempted, evidenced in their exploration and innovation.

The importance of exploratory learning for children's cognitive development is well known. Exploration not only facilitates the general learning process, by providing opportunities to discover information beyond that which can be visually obtained, it enables "new, unexplained and previously unexpected" causal mechanisms and relations to be uncovered (Bonawitz, van Schijndel, Friel, & Schulz, 2012, p.232). It is a means through which explanatory hypotheses may be

tested (Legare, 2012, 2014) and new evidence gathered when confronted with ambiguous or conflicting information (Cook, Goodman, & Schulz, 2011; Schulz & Bonawitz, 2007; van Schijndel, Visser, van Bers, & Raijmakers, 2015). Children are seen to be remarkably sophisticated and selective explorers. From preschool age, they are sensitive to pedagogical instruction, such that they appear to “explore more when they can rationally infer that there is more information to be learned” (Bonawitz, Shafto, Goodman, Spelke, & Schulz, 2011, p.329). Following demonstrations of a target function of a novel toy, pre-schoolers show reduced exploration and discovery of fewer additional toy functions compared with children in non-pedagogical conditions (who did not witness demonstrations of the target function, or witnessed an interrupted or ‘naïve’ demonstrator; Bonawitz et al., 2011). In the event that confounded information is received regarding the causal structure of a toy (e.g., it is ambiguous which toy lever operates which toy puppet), pre-schoolers are motivated to explore more than those for whom information is not confounded in an attempt to resolve such uncertainty (Schulz & Bonawitz, 2007). This enhanced exploratory response extends to situations in which inconsistent outcomes are observed (Legare, 2012). Indeed, children appear driven to explain unusual or unexpected events by increasing their exploration and hypothesis-testing towards them - generating new knowledge in turn (Legare, 2014).

Later in childhood, around 6 to 7 years of age, children demonstrate proficiency in recognising, and compensating for, under-informative individuals. Given identical demonstrations from teachers, but different prior knowledge regarding their informativeness (whether they had previously been seen to commit a ‘sin of omission’), children explore a novel toy more broadly in response to the less-informative than more-informative teacher (Gweon, Pelton, Konopka, & Schulz,

2014). In view of this evidence, it stands to reason that children will benefit from increased opportunities to explore a novel apparatus; perhaps inferring, from the provision of more time, that there are more causal connections (and functions) to be found. Findings from open diffusion experiments offer further support, wherein children's continued interaction with a task apparatus promotes exploration and allows for the appearance of innovative modifications of existing behavioural approaches within the participating playgroup (Whiten & Flynn, 2010).

Of course, there are a number of factors that play into the likelihood of children exploring (and potentially innovating) or reproducing observed information (imitating). In all of the above studies, children appear motivated to explore in response to the type or quality of information that is acquired from others. However, *personal* prior beliefs and experience also regulate learning. In Bonawitz et al. (2012), different prior beliefs induced in two groups of children regarding the balancing of an asymmetrically-weighted block overrode subsequently-presented identical evidence and prompted "distinctive patterns of exploratory play" in 6- to 7-year-olds (Bonawitz et al., 2012, p.226). The opportunity to acquire personal experience with a task before witnessing social demonstrations, and discover solutions for oneself, has a similar differential impact upon 4- to 6-year-old's exploratory behaviour. Consistent with Bonawitz et al.'s (2011) finding of restricted exploration following instruction, children given immediate social demonstrations of a solution to a novel puzzle-box task (without the chance to first interact with the task themselves) display behavioural canalisation to that solution. Unlike children who receive demonstrations *after* acquiring personal information, they were less likely to explore and innovate alternative behaviours, and optimally incorporate the social solution as one within a repertoire of others (Wood et al., 2013, 2015).

Exploratory behaviour was thus reduced by initial social demonstrations, and encouraged by successful prior, personally-acquired information. Without prior personal information, children arguably acquired a false belief that, beyond the solution demonstrated, there were no further solutions to be found (see Bonawitz et al., 2011). A clear implication of this research is that children need additional support, prompts and/or motivation to explore and innovate following the provision of social demonstrations.

An important moderator of the effect of prior experience is how difficult that experience proves to be. When young children have difficulty achieving a goal (such as opening a drawer to retrieve a toy) versus an easy experience of doing so, they are more likely to precisely imitate the adult's ensuing demonstrated means (Williamson, Meltzoff, & Markman, 2008). This is even the case when children observe a difficult experience second-hand (Williamson & Meltzoff, 2011). Interestingly, for those who have an easy initial experience, they do not discount the novel socially demonstrated means but, like the older sample of children in Wood et al. (2015), incorporate it into their behavioural repertoires in the event that their own personally-acquired means no longer proves effective (Experiment 3, Williamson et al., 2008).

Direct personal experience with a task provides important knowledge regarding one's (perceived) competency to complete it. Previous research suggests that exploration and innovation will be detrimentally impacted, and imitation enhanced, when a negative perception of one's own proficiency is gained (see Morgan, Rendell, Ehn, Hoppitt, & Laland, 2012). In the current study, all participating children had previously witnessed social demonstrations before being able to attempt the task themselves (first round of attempts, Phase 1; Carr et al.,

2015). Their experiences of ‘difficulty’, arising from variations in method efficacy, thus occurred *during* and *after* social demonstrations – not before. Rather than negatively impact their own perceived competency, low efficacy of the demonstrator’s method appeared to drive exploration and innovation (as limited as this innovation was). However, the longevity of this effect, and the propensity of individuals in higher observed efficacy conditions to innovate, given additional time and prompts to do so, is unknown.

It is evident that a range of factors, only some of which are reviewed above, regulate the degree to which children imitate or explore solutions to novel tasks. As research into the factors that facilitate innovation is still in its infancy, insights are limited. Nonetheless, various manipulations to the hook invention task (Beck et al., 2011) cast doubt on the capacity of verbal instructions (Cutting, Apperly, & Beck, 2011), suggestions (Chappell, Cutting, Apperly, & Beck, 2013), and practice with task materials (bending pipe-cleaners: Beck et al., 2011; Cutting et al., 2011) to aid innovative tool making. They rather suggest that children’s innovation difficulties arise from more intrinsic task properties (its ill-structured nature as aforementioned). We extend this research by incorporating explicit instructions and prompts to perform alternative behaviour in an innovation by modification (rather than innovation by novel invention) task. Given children’s fidelity to social demonstrations of tool use (e.g., Hopper, Flynn, Wood, & Whiten, 2010), such prompts are likely to prove more effective when they occur after, rather than before, the provision of social information¹. These prompts to try other ways to retrieve the

¹ We note that the prompts serve a fundamentally different purpose in the current study compared to tool invention studies. Here, the aim is to not to prevent children from perseverating on an incorrect response (Chappell et al., 2013), but to encourage children to deviate from the socially demonstrated behaviour (and indeed any novel behaviour they themselves attempted in the first phase of the task) to generate as many new solutions as possible and a more comprehensive picture of children’s overall ‘innovativeness’.

reward from the box, and see how many ways could be found, occurred in combination with extra attempts for the child at the task. Unlike in the first experimental phase (Carr et al., 2015), wherein only one tool insertion was permitted per attempt (thus, in effect, ‘capping’ exploration), attempts were considerably less constrained in the second phase thereby allowing for more behaviours to be enacted. We predicted that with additional opportunity (time) to explore the task, and explicit prompts to do so, children would evidence greater innovation. We made no prior predictions regarding the continuing role of efficacy (Phase 1 experimental condition) in children’s exploration and innovation. However, in line with our previous findings, we anticipated that the oldest age group of children (8-9 years) would be least likely to display continued fidelity to the (ineffective) socially demonstrated method, and most likely to produce a greater range of novel behaviours.

6.2 Method

6.2.1 Participants

Two hundred and fifty-six children (128 males), aged 4-9 years, from three primary schools in the North East of England participated. These children had all completed a first task phase with the ‘Multiple-Methods Box’ (MMB; Carr et al., 2015), a novel puzzle box from which a reward can be extracted using tools. Participants had witnessed the demonstration of a reward retrieval method that was efficacious on 0 of 8 trials (0% success condition, $N = 60$), 2 of 8 trials (25% success condition, $N = 48$), 6 of 8 trials (75% success condition, $N = 50$), or 8 of 8 trials

(100% success condition, $N = 51$). The efficacy of the method, manipulated via the discrete locking and unlocking of the exit door of the box, was mirrored in participants' own attempts with the task (Phase 1; see Carr et al., 2015, for further information). For Phase 2 of the task reported here, it was necessary to exclude data from ten children due to procedural changes in Phase 1 following their participation. These changes could be controlled in the first phase, but not in this second phase. We note that their exclusion does not bias the sample in any way; indeed, the same findings emerged from Phase 1 when analyses were re-run in their absence.

Children assigned to the control condition in Phase 1 ($N = 47$) were also not included in Phase 2 as they received no social demonstrations with the MMB. This, therefore, reduced the sample to 199 participants (98 males), separated into three age groups as in Phase 1: 4-5 years ($N = 57$, $M = 5$ years 5 months (5;5), range 4;10-5;11), 6-7 years ($N = 76$, $M = 7;0$, range 6;0-7;10), and 8-9 years ($N = 66$, $M = 8;10$, range 8;0-9;9).

6.2.2 Materials

The same novel puzzle-box task used in Phase 1, the MMB (Figure 6.1), was used in Phase 2, whereby several different tools, access points and exits could be used to remove a sticker-containing capsule. It was possible to continue examining children's novel behaviour on this task owing to the wide range of behavioural options offered. Not only were there multiple tools, access points and exits available, but these could be used in a multitude of combinations.

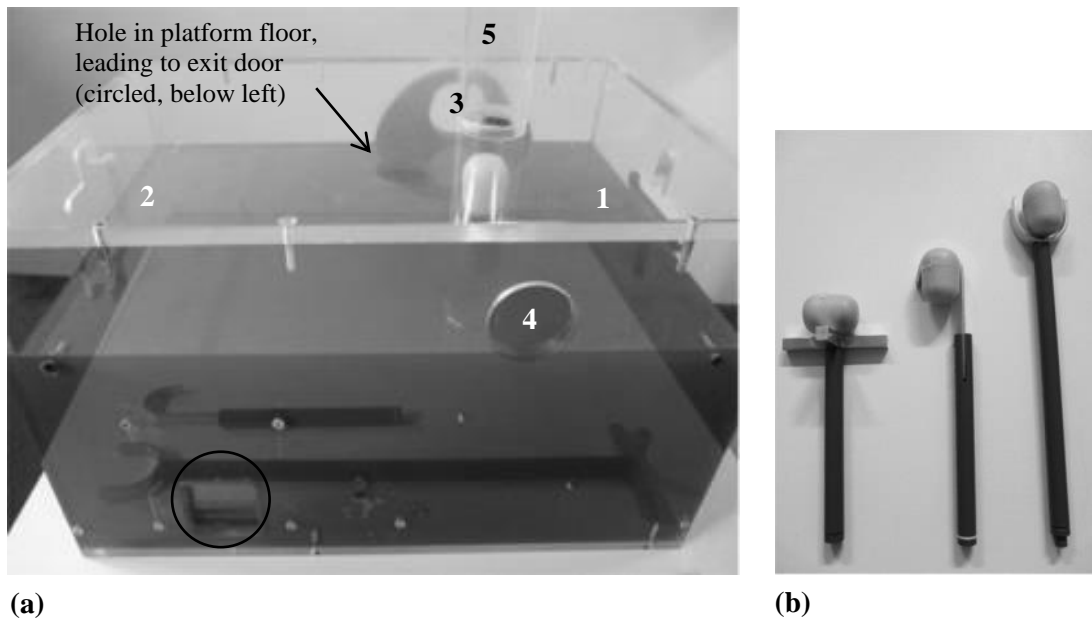


Figure 6.1. The Multiple-Methods Box (MMB) and associated tools. (a) Access points labelled 1-5: (1) ‘Social’, small inverted T-shape, used in social demonstrations, (2) ‘End’, large inverted T-shape, opposite ‘Social’, (3) ‘Dial’, circular hole, revealed by aligning the circle of a dial with a circle in the side of the box, (4) ‘Dial Opposite’, and (5) ‘Entry Chute’, a circular hole into which the reward was dropped. (b) Three tools were available, from right to left: fork, hook and sweep. The position of the capsule in relation to each tool demonstrates the main method of manoeuvre. The fork and sweep tool could be joined and used in combination to extract the reward, with the extra length affording extraction across the full length of the MMB, and can be seen in the reflection at the base of the box (a).

6.2.3 Design

Children from each age group continued to be categorised according to the experimental condition to which they were randomly assigned in Phase 1 (0% condition, $N = 50$; 25% condition, $N = 49$; 75% condition, $N = 50$; 100% condition,

$N = 51$). There was nothing to distinguish these groups, in terms of further experimental manipulations, in Phase 2 of the task.

6.2.4 Procedure

Children were tested individually in a quiet area of their school. Immediately following Phase 1 of the task, where they had up to eight attempts to retrieve capsules following the witnessed demonstrations, they received the following instructions: “I’m going to give you some more turns with the box. But this time, are there any other ways you can try to get the egg [capsule] out of the box that you haven’t tried before? See how many different ways you can find.” Between attempts, prompts such as “Are there any other ways?” were provided. These served as reminders to the participants of the new task aim (to find new ways as opposed to simply retrieving the capsule from the box, as in Phase 1).

Unlike in Phase 1 for 0-75% participants, whose experience of efficacy was manipulated via the locking and unlocking of the exit door, the door of the box was always unlocked for all participants in Phase 2. Furthermore, whereas an attempt in Phase 1 was defined as “the insertion of a tool into the box with the purposeful intention, or realisation, of making contact with the capsule prior to the tool’s extraction” (Carr et al., 2015, p.325), one attempt in Phase 2 could comprise up to five such tool insertions to allow for greater exploratory behaviour. If no outcome was produced following the fifth tool insertion (that is, the capsule was not retrieved from one of the box exits), the experimenter retrieved the stuck capsule and re-baited the box. Re-baiting of the box, whether following successful extraction on behalf of the participant or five unsuccessful tool insertions, signified the start of a new

attempt. The removal of the lid of the box, concealed by a large fabric sheet, allowed capsules to be quickly removed by the experimenter when necessary. Participants were given a maximum of eight attempt trials, over a period of five minutes. If the eight trials were not completed within this time, testing ceased.

To gain greater insight into children's preferred task behaviour as well as their affordance understanding in relation to the MMB, two questions followed participants' attempts. Behavioural responses to the first, "Can you show me the best way to get the egg [capsule] out of the box?", provided an indication of how many children, after two rounds of individual attempts and repeated permission/instructions to deviate from the socially demonstrated method, continued to adhere to what they had originally observed, and the extent to which this was influenced by the observed efficacy condition they experienced in Phase 1. The second question, "Can you tell me all the different ways you can get the egg [capsule] out of the box?", assessed both children's verbal competence in identifying different 'ways' and the number of exits they recognised in addition to the socially demonstrated door. At the end of testing all children were praised for their performance and rewarded with a sticker irrespective of their level of success (small stickers collected during testing were traded for one larger and more desirable sticker).

6.2.5 Coding and analysis

The number of (i) attempts (maximum = 8), (ii) reward extractions, and (iii) enactments of the Phase 1 socially demonstrated method (fork tool through 'Social' access point, capsule to exit door via hole in floor) were recorded. All subsequent

coding was conducted in reference to participants' behaviour in Phase 1 of the task. Four primary variables were of interest: the number of new tools, new access points, new exits, and new methods (specific combinations of tools, access points and exits) used by participants, with 'new' denoting their absence in Phase 1 of the task. However, several more nuanced measurements were noted for these variables. Specifically, we distinguished between new tools and new access points that were *discovered* (used as part of the five tool insertions per attempt but not used together with an exit to bring about an outcome, i.e., were abandoned prior to a different tool/access point being selected) and new tools/access points that were *used as part of a method* (used to manoeuvre the capsule to an exit and, on the majority of occasions, effect a successful reward extraction; exceptions include failure to open the exit door, as described below). Thus, if a tool/access point was discovered in Phase 1, but not used as a part of a reward extraction method until Phase 2, it was coded here as a new tool/access point *used as part of a method*. The discovery/method distinction was not necessary for the number of new exits given that any new exit that was discovered automatically results in an outcome (capsule extraction). With regard to the number of new methods, we distinguished between those that were successful (led to capsule extraction) and those that were produced irrespective of success (methods using the door as an exit were unsuccessful if the participant falsely believed the door to be locked or failed to discover its opening mechanism). Table 6.1 provides an overview of the variables described.

Table 6.1

Variables Subject to Statistical Analysis

Variable	Description
Attempts	Total number of attempts made (max. 8), with each attempt comprising success or up to five tool insertions
Extractions	Total number of successful reward extractions, irrespective of extraction method (max. 8)
Social Method Enactments	Total number of enactments of Phase 1 socially demonstrated method (max. 8)
New Tools/Access Points Discovered	Total number of new tools/access points attempted, but not used in successful combination with an exit to bring about an outcome (were abandoned prior to an alternative selection)
New Tools/Access Points Used in a Method	Total number of new tools/access points used in successful combination with an exit to bring about an outcome (reward extraction, or capsule to exit door)
New Exits	Total number of new exits used
New Methods	Total number of new methods (new combinations of tool, access and exit) enacted, irrespective of success
New Successful Methods	Total number of new methods (new combinations of tool, access and exit) enacted that led to successful reward extraction(s)

Note. ‘New’ denotes that the tools/access points/exits/methods were not seen in Phase 1 of the task.

From these individual variables, total scores were generated for each participant regarding the total number of new tools, access points, exits and methods used across Phases 1 and 2 of the task – critically excluding the components of the socially demonstrated method. This provided an overall measure of participants’ ‘innovativeness’. In addition, the tool, access point and exit demonstrated by the

children as the ‘best way to get the egg out of the box’ were recorded. Owing to difficulties achieving unambiguous responses to the second question (“Can you tell me all the different ways you can get the egg out of the box?”), this data was excluded.

As the data were not normally distributed, non-parametric tests were used. All statistical tests were two-tailed, and a Bonferroni correction applied where multiple follow-up tests (Mann-Whitney or Wilcoxon rank-sum) were performed to control for Type I error rates. Corrections were made for tests within, rather than across, variables given that we were interested in the nuances of children’s behaviour (that is, how they performed in relation to a number of aspects of the MMB task).

6.3 Results

Whereas all but two of the 199 participants produced the full eight attempts in Phase 1 within the five minute time limit, attempt number was slightly reduced in Phase 2 (mean number of 6.6 attempt trials, out of a maximum of 8) as a probable outcome of the more lenient attempt criteria. Nevertheless, the high number of attempts demonstrates a continued level of interest and interaction. Only one participant (a 4- to 5-year-old male) failed to produce any further attempts. There were no significant differences in the number of attempts between the sexes (Mann-Whitney $U = 4868$, $z = 0.21$, $p = .84$), ages (Kruskal-Wallis $H(2) = 3.16$, $p = .21$), or Phase 1 conditions ($H(3) = 3.46$, $p = .33$). In view of these findings, and the recognition that controlling for attempt number would not control for the number of tool insertions participants made *per* attempt, we did not standardise participants’ scores by the number of attempts they made.

As indicated by a mean number of 5.7 capsule extractions, Phase 2 attempts were not always successful. This could have been the result of continued unproductive behaviour (if the five tool insertions per attempt were exceeded, the start of a new attempt was necessitated) or failure to discover the opening of the exit door. In the first section of the results, we explore whether participants demonstrated continued fidelity to the socially demonstrated method, and whether this differed as a function of age, or, as explored in the second section, discovered novel behaviours. The third section considers the role of prior observational/personal experience of efficacy in relation to the MMB (acquired in Phase 1) on participants' subsequent innovative behaviour (in the current Phase 2). Finally, behavioural responses to the question of 'best' extraction method are investigated.

6.3.1 Did Children Continue to Reproduce the Socially Demonstrated Method in the Second Task Phase?

The majority of participants (62%; 123 of 198) performed the socially demonstrated method at least once. Compared with Phase 1, however, it was performed on fewer attempt trials (mean number of 1.97 trials in Phase 2 versus 4.89 trials in Phase 1). Given the slight discrepancy in total number of attempts between the phases, as reported above, this was not subject to statistical analysis.

Mirroring Phase 1 findings (reported in Carr et al., 2015), reproduction of the socially demonstrated method in Phase 2 was mediated by age (Kruskal-Wallis $H(2) = 12.40, p = .002$). The number of social method enactments was significantly higher for the youngest age group (4-5 years, $N = 57, Mdn = 3, SD = 3.19$) when compared with 6- to 7-year-olds ($Mdn = 1, SD = 2.16$; Mann-Whitney, $N = 76, U = 1626.00, z$

= -2.38, $p = .017$) and 8- to 9-year-olds ($Mdn = 1$, $SD = 1.52$; $N = 66$, $U = 1219.00$, $z = -3.35$, $p = .001$; see Figure 6.2). The latter two groups did not significantly differ ($U = 2148.5$, $z = -1.54$, $p = .12$). There were also no significant differences between the experimental conditions to which participants were assigned in Phase 1 ($H(3) = 4.19$, $p = .24$), wherein different experiences of demonstrated method efficacy were gained.

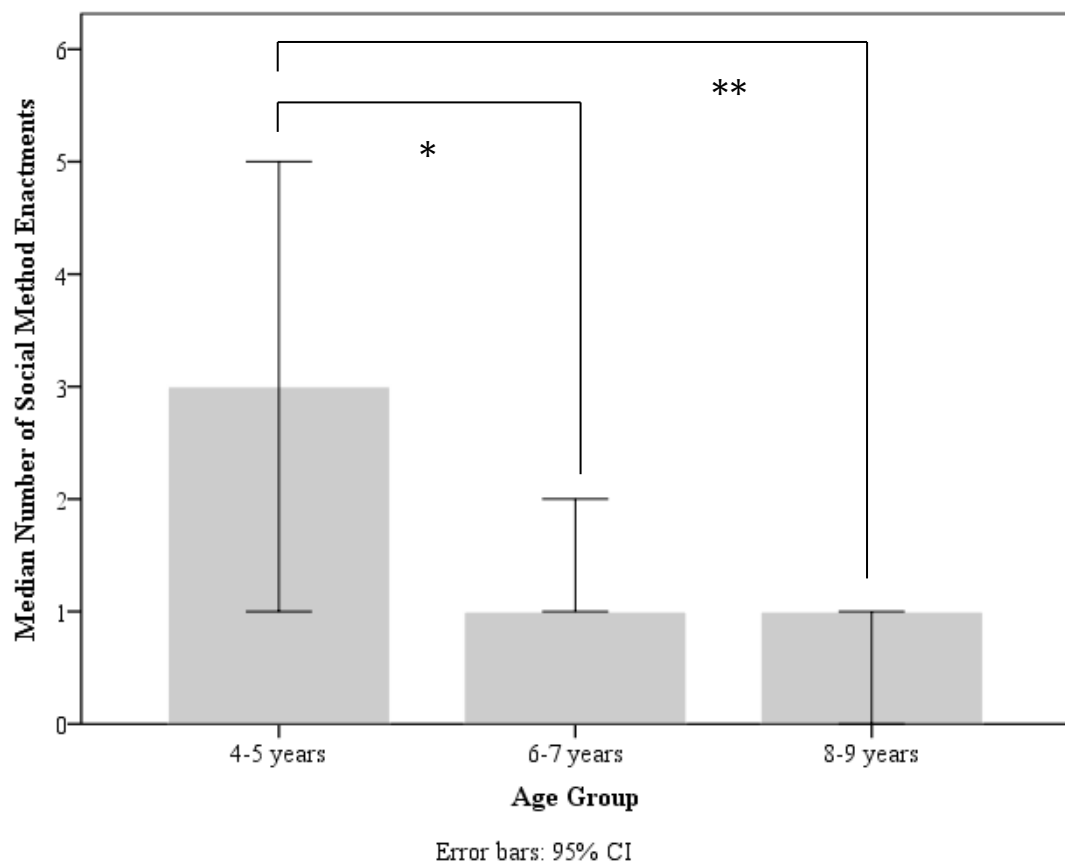


Figure 6.2. Median number of social method enactments by age group. * $p < .05$, ** $p < .005$

Age differences were also found in relation to the number of novel methods produced by participants in Phase 2 ($H(2) = 24.24$, $p < .001$) and in Phases 1 and 2 combined (total methods; $H(2) = 32.73$, $p < .001$), irrespective of method success.

Significantly fewer novel methods in Phase 2 were performed by 4- to 5-year-olds ($Mdn = 2$, $SD = 1.51$) compared to 8- to 9-year-olds ($Mdn = 3$, $SD = 14.49$; $U = 942.50$, $z = -4.85$, $p < .001$; Figure 6.3), and significantly fewer novel methods summed across Phases 1 and 2 for 4- to 5-year-olds ($Mdn = 2$, $SD = 2.04$) compared to both 6- to 7-year-olds ($Mdn = 3$, $SD = 2.19$; $U = 1476.00$, $z = -3.19$, $p = .001$) and 8- to 9-year-olds ($Mdn = 5$, $SD = 1.82$; $U = 790.50$, $z = -5.60$, $p < .001$). Six- to seven-year-olds also produced significantly fewer novel methods in Phase 2 ($Mdn = 2$, $SD = 1.81$) than 8- to 9-year-olds ($U = 1777.50$, $z = -3.04$, $p = .002$), and significantly fewer novel methods across Phases 1 and 2 when again compared to the oldest age group ($Mdn = 3$, $SD = 2.19$; $U = 1772.00$, $z = -3.04$, $p = .002$). Though the difference between the 4-5 age group and 6-7 age group was significant for novel methods in Phase 2 ($U = 1700.50$, $z = -2.16$, $p = .03$), this did not remain significant following Bonferroni correction.

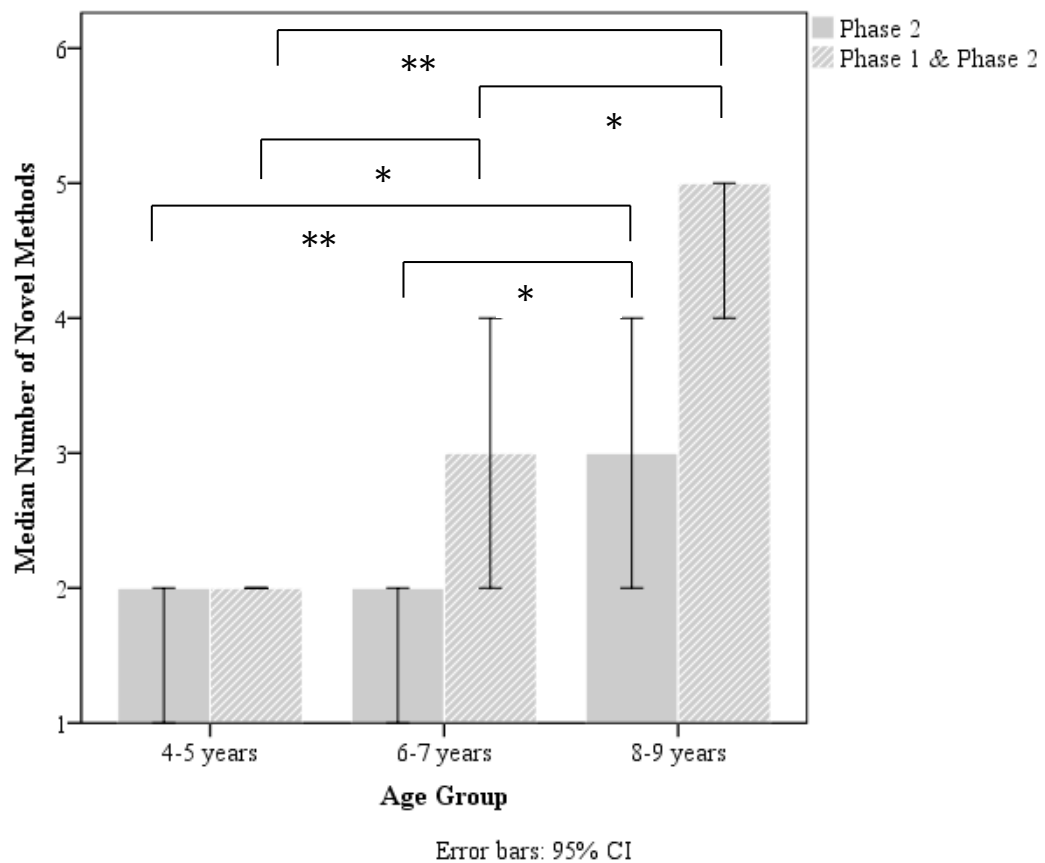


Figure 6.3. Median number of novel methods (irrespective of success), by age group, for Phase 2 and Phase 1 & 2 combined. $*p < .005$, $**p < .001$

6.3.2 Did Participants Innovate More Novel Tools, Novel Access Points and Novel Exits in Phase 2 of the Task Compared With Phase 1?

To determine whether the second phase of the task afforded participants a greater opportunity to discover alternative tools, access points and exits, comparisons of Phase 1 and Phase 2 behaviour were undertaken with Wilcoxon signed-ranks tests. However, to account for the reduced opportunities to discover these components in Phase 2, if one or more components were already discovered in Phase 1, it was necessary to calculate and analyse proportional scores. Thus, scores were calculated as a proportion of the maximum number of tools/access points/exits that

remained to be discovered (or used in a method, in line with our distinction; discounting those of the socially demonstrated method). Proportional scores were not calculated for number of new methods, given that there was no specified maximum value for this variable, or total number of tools/access points/exits discovered or used across Phases 1 and 2, as summing these scores accounted for the potentially reduced behavioural potentials at either individual phase.

Whilst there was no difference in the number of novel tools discovered in Phase 1 ($Mdn = 0.2$, $SD = 0.2$) compared with Phase 2 ($Mdn = 0.2$, $SD = 0.24$; Wilcoxon signed-ranks $z = -0.9$, $p = .37$), participants used significantly more novel tools as part of a method in Phase 2 ($Mdn = 0.2$, $SD = 0.21$) than Phase 1 ($Mdn = 0.2$, $SD = 0.15$; $z = -2.65$, $p = .008$). With regard to novel access points, participants not only discovered significantly more in Phase 2 ($Mdn = 0.25$, $SD = 0.29$) than Phase 1 ($Mdn = 0$, $SD = 0.22$; $z = -4.09$, $p < .001$), they also used significantly more in a method in the later phase ($Mdn = 0.25$, $SD = 0.27$; Phase 1: $Mdn = 0$, $SD = 0.18$; $z = -5.80$, $p < .001$). Similarly, participants used significantly more novel exits in Phase 2 of the task ($Mdn = 0$, $SD = 0.38$; Phase 1: $Mdn = 0$, $SD = 0.14$; $z = -6.27$, $p < .001$), and enacted significantly more new methods ($Mdn = 2$, $SD = 1.71$; Phase 1: $Mdn = 1$, $SD = 1.23$; $z = -7.51$, $p < .001$). It would not be appropriate to consider the number of *successful* methods in this case, as success was manipulated in Phase 1 by the locking/unlocking of the exit door.

A significant difference in the ‘type’ of innovations performed by participants was observed in Phase 1 of the task; specifically, they discovered significantly more novel tools throughout their attempt trials than access points or exits (and significantly more novel access points than novel exits). This finding was reproduced here, both when incorporating the new tools/access points *discovered*

variables (Friedman's ANOVA $\chi^2(2) = 10.64, p = .005$) and the new tools/access points *used in a method* variables ($\chi^2(2) = 8.70, p = .013$). We term new discoveries 'used in a method' as reflective of innovation (if we postulate that innovations should be successful; Carr et al., accepted). In the current study (Phase 2) we found that participants innovated significantly more access points ($Mdn = 0.25, SD = 0.27$) than tools ($Mdn = 0.20, SD = 0.21; z = -3.22, p = .001$). The difference between exits ($Mdn = 0, SD = 0.38$) and access points ($z = -0.53, p = .60$), and exits and tools ($z = -1.28, p = .20$), was not significant.

Examining the total number of tool, access point and exit innovations performed by participants across Phases 1 and 2 (with the raw as opposed to proportional scores), significant differences remained in the 'type' of innovations produced ($\chi^2(2) = 36.61, p < .001$). This was specifically evidenced by a significantly greater total number of tool innovations ($Mdn = 1, SD = 1.04$) compared to exit innovations ($Mdn = 0, SD = 1.20; z = -5.63, p < .001$), and significantly greater access innovations ($Mdn = 1, SD = 1.18$) again compared to exit innovations ($z = -4.50, p < .001$). There was no significant difference in the total number of tool innovations and access point innovations made by participants ($z = -1.78, p = .07$).

To investigate whether there was a relation between the number of tool, access point and exit innovations produced in Phases 1 and 2 (that is, whether children were consistent in achieving low or high levels of innovation across task phases), correlational analyses with proportional scores were undertaken. Whilst no correlations between Phase 1 and Phase 2 innovative behaviour were found in relation to tools (Spearman's $r_s = -0.10, p = .15$), access points ($r_s = 0.11, p = .12$) or methods ($r_s = 0.13, p = .08$), although the latter was approaching significance, a

significant positive correlation was found between the number of exit innovations produced in Phase 1 and Phase 2 ($r_s = 0.29, p < .001$).

6.3.3 How Did Efficacy of the Social Method in Phase 1 Affect Subsequent Innovation?

The focus in Phase 1 was on participants' level of exit innovation, given that modifications to the exit were the only way in which behaviour could be made more efficacious, yet low rates of exit innovation were observed. We were thus interested to discover whether more individuals went on to discover alternative exits when provided with additional attempts at the MMB task in the current Phase 2. Out of 175 participants who did *not* discover a novel exit in Phase 1 (i.e., any exit other than the socially-demonstrated door), 46 went on to discover at least one novel exit in Phase 2. This equates to a discovery rate of 26.3%, a marked leap from the 12.4% reported previously for Phase 1. With regard to the 24 individuals who did discover at least one novel exit in Phase 1 ($N = 26$ in Carr et al., 2015, but two removed due to aforementioned procedural changes), 13 of these (54%) went on to discover at least one *more* novel exit in Phase 2 of the task.

Using proportional scores, the number of exit innovations produced in Phase 2 was not seen to be significantly affected by Phase 1 condition (Kruskal-Wallis: $H(3) = 2.63, p = .45$), but was significantly affected by age ($H(2) = 8.01, p = .018$). Children aged 4-5 years produced significantly fewer exit innovations in Phase 2 ($Mdn = 0, SD = 0.30$) than children aged 8-9 years ($Mdn = 0, SD = 0.46; U = 1418, z = -2.36, p = .018$). However, this was only approaching significance following Bonferroni correction (corrected $p = .017$). Children aged 6-7 years also produced

significantly fewer exit innovations ($Mdn = 0$, $SD = 0.35$) than the oldest age group (Mann-Whitney $U = 1895$, $z = -2.43$, $p = .015$). There was no difference between 4- to 5-year-olds and 6- to 7-year-olds ($U = 2133.5$, $z = -0.02$, $p = .98$). The distribution of Phase 2 innovators, across sex, age, and condition can be seen in Table 6.2.

Table 6.2

Number of Phase 2 Exit Innovators According to Three Categories of Participant Characteristics (Age, Sex, and Phase 1 Condition)

Participant Characteristics	Number
4-5 years	13
6-7 years	14
8-9 years	19
Male	25
Female	21
0% success	9
25% success	10
75% success	17
100% success	10

Participants' discovery of novel access points ($H(3) = 4.89$, $p = .18$), and use of these access points in methods ($H(3) = 3.31$, $p = .35$), in Phase 2 was not significantly influenced by Phase 1 condition, nor was the total number of access points innovated across phases (raw scores; discovered: $H(3) = 1.71$, $p = .63$; used in methods: $H(3) = 2.44$, $p = .49$). This was not so for the use of tools. Significant differences between Phase 1 efficacy conditions were uncovered when looking at the number of novel tools discovered in Phase 2 ($H(3) = 8.46$, $p = .04$), novel tools used in methods in Phase 2 ($H(3) = 10.91$, $p = .01$), and total number of tool innovations across the phases (raw scores; for tools used in methods only, see Figure 6.4: $H(3) =$

8.19, $p = .04$). Looking specifically at tools used in a method, given its closer association with innovation as aforementioned, participants who experienced 0% success with the socially demonstrated method in Phase 1 produced significantly fewer tool innovations in Phase 2 ($Mdn = 0$, $SD = 0.16$) compared with participants who experienced 100% success ($Mdn = 0.2$, $SD = 0.23$; $U = 820.5$, $z = -3.27$, $p = .001$). All other condition comparisons were non-significant, or became so following the application of Bonferroni corrections. Likewise, participants assigned to the 100% condition in Phase 1 ($Mdn = 2$, $SD = 1.07$) produced significantly more tool innovations across Phase 1 and 2 than participants assigned to the 0% condition ($Mdn = 1$, $SD = 0.89$; $U = 886.50$, $z = -2.78$, $p = .006$). This difference in rates of tool innovation between conditions was not evident in Phase 1.

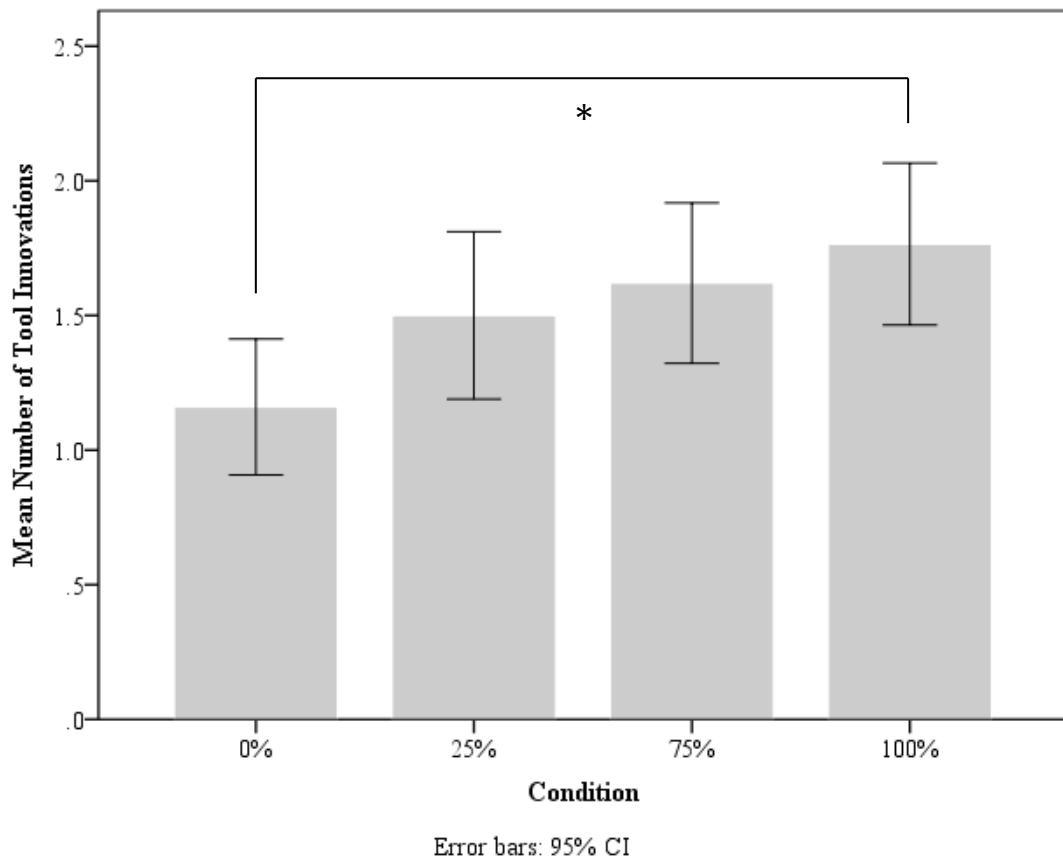


Figure 6.4. Mean number of tool innovations (used as part of a method) across Phases 1 and 2 of the task by experimental condition. Although non-parametric statistics were conducted, the means are displayed here given that the median score for the 25%, 75% and 100% group was 2. * $p < .05$

A significant effect of Phase 1 condition was found when examining the number of novel methods produced by participants in Phase 2 ($H(3) = 9.04$, $p = .03$), and number of these methods that were successful in extracting the capsule ($H(3) = 9.57$, $p = .02$). Individuals assigned to the 75% demonstrated success condition in Phase 1 produced significantly more novel methods in Phase 2 ($Mdn = 2$, $SD = 1.85$) compared to those in the 0% condition ($Mdn = 2$, $SD = 1.69$; $U = 839.00$, $z = -2.88$, $p = .004$). Though participants in the 0% condition also produced fewer novel methods

than those in the 100% condition ($Mdn = 2$, $SD = 1.61$; $U = 971.00$, $z = -2.10$, $p = .035$), this was not significant following Bonferroni correction.

6.3.4 Did Participants' Prior Experience of Efficacy Influence Their Selection of the 'Best' Tool, Access Point, and/or Exit?

Each component that formed a part of the socially demonstrated method (fork tool, 'Social' access point, exit door) were demonstrated as 'best' by the majority of participants (tool = 59.2%, access = 70.4%, and exit = 73.6% respectively). Importantly, however, this meant that 80 participants deviated from selecting the fork tool, 58 from the 'Social' access point, and 52 from the exit door. Participants' Phase 1 condition did not significantly affect their choice of 'best' tool (Pearson chi-square, $N = 196$, $\chi^2(3) = 1.06$, $p = .79$) or 'best' access point ($N = 196$, $\chi^2(3) = 1.63$, $p = .65$), but did affect their choice of 'best' exit ($N = 197$, $\chi^2(3) = 8.41$, $p = .04$). Investigating this result further with chi-square tests of the possible pairwise comparisons, participants in the 0% demonstrated success condition significantly differed in their selection of 'best' exit compared to participants in the 100% condition ($\chi^2(1) = 8.19$, $p = .004$, Bonferroni corrected $p = .008$). As can be seen in Table 6.3, participants who experienced 0% success with the exit door in Phase 1 were significantly less likely to select the door (and more likely to select an alternative exit) compared with participants who experienced 100% success with the exit door in Phase 1.

Table 6.3

Participants' Demonstration of the 'Best' MMB Exit According to the Experimental Condition to Which They Were Assigned in Phase 1

Efficacy of door	Door selected	Alternative exit selected
0%	32	18
25%	33	13
75%	35	15
100%	45	6

In selecting a method to demonstrate as 'best', most participants (161 of 196; 82%) opted to demonstrate a method they had performed previously (either in Phase 1 or Phase 2 of attempts, or both). Hence, 35 participants performed a brand new method. Interestingly, whereas 25 of these demonstrated a novel combination of actions with an exit they had already discovered, 10 individuals demonstrated a method accompanied by an exit innovation (that is, these 10 participants had used only the door as an exit in Phase 1 and 2, but used a new exit (one of the top holes of the box) when asked to show the 'best' method to extract the reward).

6.4 Discussion

Following the provision of social information and opportunity to acquire personal experience with a novel puzzle-box task (Phase 1; Carr et al., 2015), the current study provided 4- to 9-year-old children with additional time to interact with the MMB, along with reduced constraints (more lenient attempt criteria; allowing children up to five, rather than just one, tool insertion per attempt) and explicit instructions and prompts to try other/different ways. These manipulations were

designed to allow for a more comprehensive and ecologically-valid understanding of children's exploration and innovation abilities. The findings provide a strong indication that experimental approaches with short timeframes in which novel behaviour may be evidenced will underestimate children's capacity to innovate. Not only did children demonstrate reduced fidelity to the Phase 1 socially demonstrated method in Phase 2 of the task, by enacting the observed method on fewer attempt trials, they also produced a greater number of tool, access point and exit innovations in the later phase, evidencing successful exploratory learning. Effects of age and Phase 1 experimental condition were also found, and explained below.

6.4.1 Fidelity to the Phase 1 Socially Demonstrated Method

Overall, participants displayed reduced fidelity to the socially demonstrated method (observed prior to their first round of attempts in Phase 1) when provided with additional attempts at the task. This was not an effect of memory, as the majority of participants reproduced the social method at least once in Phase 2 and identified its tool (fork), access point ('Social') and exit (door) action components as the 'best way' to retrieve the reward. Having had the opportunity to pursue affiliative (social) and/or instrumental (learning) goals through faithful imitation in the first phase of the task (see Over & Carpenter, 2013), and acquire understanding and personal experience of social method efficacy, children produced less imitation in the second round of attempts. When explicit encouragement was given to consider *other* ways to retrieve the egg from the box, this highlighted the opportunities for further information gain through individual exploration. In combination with our Phase 1 findings (Carr et al., 2015) and the current exploration findings (Section

6.4.2), it appears that there was a trade-off between instruction and exploration, akin to that reported by Bonawitz et al. (2011), in the first phase of the task when participants' attempts immediately followed social demonstrations. In this way, social information initially limited children's 'hypothesis space' (Schulz, 2012) wherein novel behaviour could be considered.

Mirroring Phase 1 findings and supporting the competence interpretation previously advanced (Carr et al., 2015), the observation of lowered imitation fidelity appeared driven by developmental advances in cognitive capacity and/or flexibility to produce novel alternative behaviour with age – and thus also potentially inhibit copying of what was observed. The association between innovation and age has been noted elsewhere, in both human children (Beck et al., 2011) and non-human primates (e.g., Kendal, Coe, & Laland, 2005; Reader & Laland, 2001). Whilst these results suggest that younger children are more susceptible to the social motivations and pressures of imitation, opposite evidence is found in the array of studies documenting selective copying at preschool age, the imitation of inefficient tool use by older, but not younger, children (DiYanni, Nini, & Rheel, 2011), and increasing 'over-imitation' from childhood into adulthood with causally ambiguous tasks (McGuigan, Makinson, & Whiten, 2011).

In addition to demonstrating the highest levels of (continuing) imitation, the youngest participants (4-5 years) produced significantly fewer novel methods in Phase 2, and Phases 1 and 2 combined, than the older age groups. Thus, whilst it is possible that young children possess greater flexibility in their exploration than older children (Gopnik, Griffiths, & Lucas, 2015), owing to their reduced bias for existing knowledge, this does not play out in their interactions with more complex instrumental tasks such as the MMB. The oldest participants (8-9 years), by

comparison, were the most proficient in producing Phase 2 exit innovations. Exit innovations were regarded of most importance in Phase 1 given their capacity to change the outcome of the task: the top access points of the box are not reliant upon whether the exit door opens. Though the exit door was always unlocked in Phase 2, we had intended to prompt the use of alternative exits with reference to “different ways to get the egg *out* of the box”. The capacity to produce novel modifications to pre-existing behaviour, increasing solution efficacy in Phase 1 and behavioural diversity in Phase 2, is vital for cumulative culture (Tennie, Call, & Tomasello, 2009). This capacity is arguably of even greater value when it is not reliant upon the previously-acquired behaviour becoming redundant or non-functional (as has been examined in non-human primates; see, for example, Hrubesch, Preuschoft, & van Schaik, 2009; Lehner, Burkart, & van Schaik, 2011). Of course, it must be acknowledged that environmental variability and change, that serves to alter the availability of behavioural options, is a major source of behavioural flexibility (Lefebvre, Whittle, Lascaris, & Finkelstein, 1997) and is even hypothesised to potentially underlie the evolution of human’s cultural capacity (Richerson & Boyd, 2005). Children evidence behavioural flexibility in seeking multiple alternative ways to solve a task, even when a demonstrated method is viable (current study; although the unlocking of the door may not have been discovered by some children for whom it was locked in Phase 1), and by flexibly incorporating multiple task solutions into their behavioural repertoires (Wood et al., 2013, 2015).

6.4.2 Exploration: Impact of Opportunity and Initial Observed Behaviour Efficacy

In line with our hypothesis, children evidenced greater exploration (here, akin to discovery of novel action components) and innovation (successful use of novel action components in a reward extraction method) with increased opportunity to explore the MMB task and explicit prompts to do so. Controlling for the potentially reduced number of behavioural options available in the later phase, participants discovered and used more access points in Phase 2 compared with Phase 1, as well as using more novel exits and enacting a greater number of new methods. Whilst no more tools were discovered in Phase 2 than Phase 1, participants were able to more effectively use them to bring about an outcome (turning tool exploration into tool innovation). With the extra experience afforded by exploration, children were plausibly able to discover additional action possibilities, or ‘affordances’ (Gibson, 1977), in relation to the properties of the MMB, but also particularly with regard to the tools (perhaps owing to the greater variability in their length and shape).

The increased discovery and use of action components in Phase 2 supports findings from the substantial literature on children’s exploration. Exploration supports learning (e.g., Bonawitz et al., 2012; Piaget, 1930; Singer et al., 2006) by engendering, in the current study, an appreciation of how action components may successfully be used. Moreover, with greater opportunity to explore a novel object, and continued motivation to do so, children seek to gather new and relevant information in a manner analogous to play (Gopnik & Wellman, 2012), and children continue exploring when they infer (or, in our case, are indirectly informed via

prompts) that there is more to be learned (Bonawitz et al., 2011) and when personal attempts at a task can be made (Wood et al., 2013, 2015).

It is not only greater understanding of object properties (or functional affordances) that children gain through exploration, regarding, for example, the suitability of tool shapes and lengths for given access points (reducing their random and unsuccessful application), but causal knowledge (Cook et al., 2011). This was of relevance for Phase 1 wherein some children (25% and 75% success conditions) were confronted with an exit door that opened on some occasions but not others, with no obvious explanation for the discrepancy. Given that causal ambiguity and unexpected events are seen to prompt selective exploration (Cook et al. 2011; Legare, 2012; Schulz & Bonawitz, 2007), we might have expected different patterns of exploration, and ultimately innovation, for those children who initially experienced uncertainty in the social method (25% and 75% conditions) compared to those who did not (0% and 100% conditions) – if social information continues to impact children's behaviour over time (i.e., in the second task phase). Whilst we found some support for differences in exploration and innovation between Phase 1 conditions, this was limited.

We provide three explanations as to why more extensive support was not uncovered in this regard. First, unlike other studies (e.g., Cook et al., 2011), it was not physically possible for children to uncover the causal mechanism controlling the exit door (it was manipulated via a remote control device), meaning exploration that was theoretically directed towards uncovering causal relations could not be accurately defined or inferred. Second, the exit door was unlocked throughout Phase 2. Depending upon whether this was recognised by children, this would have resulted in differing beliefs regarding the necessity of new behaviour and arguably

the type of exploration that was required. Had the exit door continued to be locked or unlocked in line with participants' Phase 1 condition, a greater effect of prior experience upon exploration may have been seen. Third, as will be discussed, there are various explanations (aside seeking to uncover causal relations) as to why participants may have explored differently in Phase 2.

The differences uncovered in Phase 2 as a result of Phase 1 condition suggest that observing efficacious behaviour facilitates subsequent exploration. Participants previously assigned to the 75% success condition produced significantly more novel methods than participants assigned to the 0% condition, and 100% participants were significantly more likely than 0% participants to explore (and innovate) tools in Phase 2 and Phases 1 and 2 combined. This enhanced exploratory effect for children in higher-efficacy conditions was only seen with regard to two outcome variables, therefore the result cannot be overly emphasised. Nonetheless, they require explanation. It may have been that these children were simply more bored in the second task phase having had greater success with the social method in the first, prompting a heightened exploratory response. It is also possible that lack of success with the social method was normalised for 0% participants (and to a lesser extent 25% participants), who observed the experimenter repeatedly failing to extract the reward. This may have reduced their expectations of discovering novel behavioural alternatives. This supposition is counteracted somewhat, however, by the greater discovery of novel exits for 0% participants in the first phase of the task, evidencing adaptive increase of solution efficacy.

As we proposed in Carr et al. (2015), the 75% and 100% participants can plausibly afford to explore *more* than the 25% or 0% participants in the knowledge that they already have a functional method in their repertoire; thus, potentially better

ways of accomplishing the goal could be sought, with the social method kept in reserve. Consistent with Legare's (2012) observation of children exploring more in an effort to resolve unusual events, children in the 75% success condition produced a greater number of novel methods than children in the 0% success condition. Yet, if increased exploration follows inconsistent outcomes, it is unclear why this would not also be the case for 25% participants who likewise experienced uncertainty in the success of the social method. Here, it is probable that there is an interaction with confidence: greater confidence is gained with the knowledge that one already has a (largely) functional method in one's behavioural repertoire. The 25% and 75% conditions are united in causal ambiguity, but potentially disparate in confidence-inducing effects. Participants' perceptions of self-efficacy (Bandura, 1997), altered by observed behaviour efficacy, could impact upon competency beliefs, intrinsic motivation, achievement behaviours (such as persistence), with ultimate behavioural consequences for performance (see, for example, Eccles & Wigfield, 2002).

It appears that there is a subtle distinction between encouraging directed innovation by showing children behaviour that is low in efficacy (increasing the likelihood that they solve the exit door problem; Phase 1), and encouraging more general exploration by showing children behaviour that is *high* in efficacy (such that they try out, in the present case, a greater number of new methods and tools). Children appeared to innovate by necessity in Phase 1, in order to meet the goal of retrieving the capsule from the box. In Phase 2, the instructed goal was to find *other* ways to retrieve it. There may have been more of a role for intrinsic motivation and confidence in the later phase, accounting for the variation in between-condition effects. Importantly, as earlier stated, these effects are not generalisable to all

outcome variables. What we may have captured is simply variation in individual children's proclivity for some forms of exploration.

6.4.3 Innovation: Rates and Types

Unlike in Phase 1, rates of exit innovation in Phase 2 were not affected by efficacy condition, supporting the exploration-innovation distinction outlined above (and the instilment of discrete phase goals). With roughly equal numbers of exit innovators found across age, sex and condition groups, it appears that it was the extra time, attempts and explicit instructions/prompts that drove the increased rates of exit innovation in Phase 2; not, as in Phase 1, experience of social method efficacy. However, when asked to demonstrate the "best way to get the egg out of the box", those who had previously experienced 0% success with the exit door were significantly less likely to demonstrate it as a 'best' exit than those who had experienced 100% success with the exit door. Thus, whilst prior experience of efficacy did not serve to differentially increase or decrease use of novel exits in Phase 2, that experience had a lasting influence – so much so, that children for whom the exit door was always problematic dissented from selecting (that is, demonstrating) the same exit as the experimenter. This is a presumably difficult act given children's desire to affiliate (Over & Carpenter, 2013).

Rates of exit innovation were, however, significantly affected by task phase. Whereas only 24 individuals of the current sample innovated by discovering at least one novel exit in Phase 1, 46 *more* went on to innovate in this way in Phase 2. As children were not explicitly informed about the unlocked exit door in Phase 2, but had to discover this for themselves, it is not possible to definitively know whether

children innovated out of presumed necessity (still regarding the exit door as unreliable) or whether the increased innovation was a result of children's greater exploration. The significantly higher rates of tool and access point innovations, which accompanied the higher rates of exit innovations, would appear to support the latter proposal. It is also intuitive that the more time and opportunity one has to explore, the greater the likelihood of making innovative discoveries. This is reflected in open diffusion experiments, whereby innovative modifications to 'seeded' behaviour emerge with time and repeated opportunities to interact with a novel apparatus (Whiten & Flynn, 2010).

Across both phases, more tool and access point innovations were produced than exit innovations. Children ostensibly continued to struggle with conceptualising the top holes of the box as exits after they have been observed as access points, an observation that is fitting with the difficulties incurred by functional fixedness. Functional fixedness, the fixation upon the demonstrated or learned design function of an object as the proper, conventional or normative way to use it, is seen to present a very real challenge for children's problem solving following demonstrations of tool or object use (e.g., German & Defeyter, 2000; German & Barrett, 2005; Hernik & Csibra, 2009). Seeing an object, or a component of that object, as 'for' a particular function will necessarily constrain alternative and *creative* conceptions of its possible uses (Defeyter, Avons, & German, 2007). This will be a crucial phenomenon to target in efforts to enhance and promote innovative problem solving.

Interestingly, there was some evidence of consistent individual differences in children's (exit) innovativeness. Correlational analyses revealed that those who innovated more exits in Phase 1 also innovated more exits in Phase 2. Moreover, half of the Phase 1 exit innovators continued to be innovative in Phase 2 by discovering

at least one more novel exit. Though this could be hinting at the possibility of an innovative trait, with some children appearing to be more consistently innovative than others, it might also be an effect of learning: that is, learning that the top holes of the box can function as exits as well as access points. With repeated prompts, those who have this knowledge go on to use more of them. We have provided support elsewhere (Carr, Kendal, & Flynn, in prep: Chapter 4) for some consistency in children's behaviour on tasks assessing constructs related to innovation, but this is more likely a domain-specific propensity for some children to engage in individual learning (as opposed to an explicit propensity for innovation). Nevertheless, this would help account for the findings uncovered here.

6.4.4 Summary

Supporting our hypothesis, participants demonstrated greater exploration and innovation in the second phase of the task compared with the first. This may have been the result of one or a combination of factors, including: increased time to explore the MMB, enabling further opportunities for affordance learning (and possibly causal learning); explicit instructions and prompts to try different ways, simultaneously promoting deviation from observed behaviour and overcoming issues of permission; enhanced task-related knowledge and confidence owing to prior personal attempts; or simply greater 'distance' from social information, thereby reducing its salience. Future studies are required that isolate and observe the effects of these individual variables. It would be interesting to discover if instructions and prompts to explore and try "other ways" has a differential impact upon novel behaviour production that occurs in the aftermath of social demonstrations (whilst

suggested here, its effects cannot be untangled from that of the additional manipulation of time). Moreover, the role of instruction has typically been examined as a component of instrumental skill acquisition, along with social and pedagogical learning. Yet there is also clearly the potential to exploit children's sensitivity to instruction by encouraging deviation from information that is known to seeking information that is *unknown*.

In addition to phase effects, age effects were uncovered that were complementary to those previously reported (Phase 1; Carr et al., 2015) and support a competency-based interpretation of the ontogenetic development of innovation. Finally, whilst there was reduced fidelity to the Phase 1 socially demonstrated method, there was evidence of some lasting effect of social information, evident in the (selectively) enhanced exploration of 75/100% participants and demonstrations of 'best' reward exit. These findings add to the cautionary research of Bonawitz et al. (2011) and others regarding the use of social information and its capacity to constrain and limit the discovery of novel information.

Findings of the prior study (Carr et al., 2015) and current study intriguingly hint at the potential for social information quality to impact upon children's subsequent exploration and innovation in qualitatively different ways; with low observed behaviour efficacy appearing to prompt innovation (Phase 1), and high observed behaviour efficacy prompting more general exploration (new tools and methods only; Phase 2). This corroborates reasoning regarding the theoretical distinction of exploration and innovation (e.g., Reader & Laland, 2003). If exploration leads to innovation (Carr et al., accepted), however, we might have expected the higher-efficacy participants to have not only explored but innovated at a significantly higher rate. Yet, this was only seen to be the case with tool innovations

for 100% participants. We cannot rule out the proposition that exploration leads to innovation (by promoting new learning) on the basis of only two significant findings regarding efficacy condition and exploration. Future work is clearly required to more fully address these relations. Follow-up studies are also required wherein no time limit is imposed (perhaps only limiting attempt number) in order to observe children's truer capabilities, and investigations into the role of motivation and confidence in children's exploration and/or innovation.

In order to avoid hasty deductions and ultimately underestimations of children's innovative capacities, a movement is needed toward experimental procedures that more accurately reflect the contexts and environments in which novel behaviour is produced, such as open diffusion studies over extended time periods. Allowing more time for innovation, particularly in the aftermath of social demonstrations, is a clear first step.

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Chapter 7

General Discussion

This thesis aimed to investigate childhood innovation. This work was undertaken in a limited, albeit growing, field of research and knowledge regarding children's ability to produce novel behaviour, an ability which is integral to human's cultural success and future capacity to adapt. Specifically, the thesis addressed questions relating to: (i) what it means to innovate; (ii) when children innovate, as a function of both development and context; (iii) who innovates, and whether there is consistency in individual differences; (iv) which factors appear to facilitate the appearance of innovation; and, finally, (v) how innovation may be enhanced and promoted. The discussion provides an integrated overview of the findings, addressing how they contribute to, and have wider implications for, our understanding of innovation from cognitive, developmental and cultural evolutionary perspectives. It concludes with a consideration of the applications of the current work, its limitations, and future directions.

7.1 Childhood Innovation Critically Develops with Age

Children demonstrate an early-emerging capability to not only use tools (McCarty, Clifton, & Collard, 2001; Rat-Fischer, O'Regan, & Fagard, 2013), but to acquire enduring tool categories (Phillips, Seston, & Kelemen, 2012), understand tool functionality and design (Casler & Kelemen, 2005; Hernik & Csibra, 2015), utilise causal information and feedback to guide tool-based learning (Bechtel, Jeschonek, & Pauen, 2013), and faithfully acquire (McGuigan, Whiten, Flynn, &

Horner, 2007) and transmit (Hopper, Flynn, Wood, & Whiten, 2010) tool-use behaviour following its observation. However, in spite of such sophisticated skills, it appears that children's ability to *innovate* in this domain is limited. Corroborating existing accounts of the infrequency of innovation in early and middle childhood (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; Hanus, Mendes, Tennie, & Call, 2011; Nielsen, 2013), findings from Chapter 3 document that only a small percentage of children (12.4%) aged 4-9 years innovated by discovering a novel exit to that demonstrated by an experimenter on the Multiple-Methods Box (MMB) task. This was despite some children witnessing a reward retrieval method that was never effective (0% success condition) or variable in its effectiveness (25% and 75% success conditions) with regard to achieving the task goal. The findings from Chapter 3 extend those of existing studies by suggesting that innovation in the aftermath of social demonstrations (akin to innovation by modification) is challenging even beyond middle childhood (8-9 years; see the following section for a discussion of the implications of this finding). Nevertheless, in an important and novel discovery, instances and rates of children's innovation on the MMB task were enhanced with increased time and explicit instructions to explore (Chapter 6).

As Legare and Nielsen (2015) state, there are a number of compelling reasons why children, and young children *particularly*, should possess tool innovation capabilities. For example, beyond those set out earlier regarding children's early use and understanding of tools, younger children are ostensibly less constrained by existing knowledge than older children, enabling them to better use task evidence to more accurately select between abstract causal hypotheses (Gopnik, Griffiths, & Lucas, 2015). Moreover, younger children are less susceptible, or more 'immune', than older children to effects of functional fixedness (Defeyter &

German, 2003; German & Defeyter, 2000), wherein the learned design function of an object hinders consideration of its novel alternative use. Two recent studies raise the possibility that innovation skills are indeed present in young, specifically preschool-age, children (Subiaul, Krajowski, Price, & Etz, 2015; Tennie, Walter, Gampe, Carpenter, & Tomasello, 2014), considerably earlier in development than has been reported elsewhere. There are some important discrepancies to note, however, between the innovation that is required in these and other (e.g., Chapter 3, Chapter 5; Beck et al., 2011) studies. First, Subiaul et al. (2015) examine innovation that is achieved through ‘summative imitation’; that is, the novel combination of different actions performed by different models (see also Section 7.2). As the novelty is evident in action combination, it transpires that the actual behaviours to be combined (allowing compartments of a puzzle box to be opened for reward retrieval) have already been individually observed. Thus, there is no novel behaviour production as such. Second, in the case of Tennie et al. (2014), 4-year-old children in diffusion chains were seen to innovatively modify an inefficient observed means of completing a task (transporting dry rice). However, not only did this require selecting an alternative pre-made and obviously available tool, as opposed to the novel modification or production of a tool/tool-use behaviour, but such alternative tool selections were only found when children observed the inefficient tool use of peers as opposed to adults. This is in keeping with a ‘copy adults’ bias that is known to be salient for young children (Wood, Kendal, & Flynn, 2012), and could be partially responsible for the low rates of innovation observed in Chapter 3 (given the presence of an adult demonstrator). These considerations are not, however, to diminish the contributions of these studies; clearly, they are important illustrations of the beginnings of cumulative cultural capabilities in young children. Rather, these

considerations are intended to emphasise the imperative relation between the form of innovation that is being assessed, implicating factors such as task difficulty and associated cognitive requirements, and abilities or developmental trajectories that are observed (Section 7.2).

As with other studies examining novel behaviour production (e.g., Beck et al., 2011), no evidence was found here of a facilitatory effect of young children's potentially greater flexibility upon innovation (or exploration). Thus, whilst "the apparent limitations in children's knowledge and cognitive abilities may actually sometimes make them better learners" (Gopnik et al., 2015, p87), the advantages possessed by younger children in this regard do not appear sufficient to aid innovation, which additionally requires capabilities that develop throughout childhood (such as enhanced information processing and executive functions, which are necessarily implicated in novel problem solving). As a result, older children's bias for existing knowledge and their susceptibility to functional fixedness necessarily compounds appearances of innovation when their otherwise enhanced cognitive capacities would better allow for them.

A reliance on, and apparent reluctance to deviate from, the observed behaviour of adults, as seen in Chapter 3 and to a lesser extent in Chapter 6 (following explicit instructions to explore and find "other ways"), is consistent with children's established proclivity for social learning and their (evolved) bias toward ostensive signals of communicative acts (natural pedagogy: Csibra & Gergely, 2009). Adults normatively expect children to learn (Tomasello, 2016), and this is communicated through instruction or pedagogy. A bias for social learning in childhood may be considered adaptive in view of the large number of instrumental skills and cultural behaviours that must be acquired, both to allow individual survival

and success and to demonstrate affiliation with one's social group (Legare & Nielsen, 2015; Uzgoris, 1981). High fidelity imitation also permits the learning of cognitively opaque artefact use and cultural practices (Gergely & Csibra, 2006) which are prevalent in human societies (Boyd, Richerson, & Henrich, 2011), thus making even 'over-imitation' (the reproduction of causally irrelevant actions; Lyons, Young, & Keil, 2007) an adaptive learning strategy. From a cultural evolution perspective, social learning is also less 'costly' than asocial/individual learning (Boyd & Richerson, 1985), at least when there are some asocial learners in the population tracking environmental variability.

Children, thus, appear distinct from other animal species who have been thought to "use social information primarily as plan B, or a backup when personal information is too costly to obtain, unreliable or outdated" (Rieucou & Giraldeau, 2011, p.950; Kendal, Coolen, & Laland, 2009). Nevertheless, this thesis has presented evidence for adaptive informational trade-offs in children's learning (increased rates of innovation in response to inefficacious observed behaviour; Chapter 3), along with preliminary evidence for behavioural consistency in children's propensity (or preference) to engage in asocial/individual learning (Chapter 4). This latter result resonates with findings of consistency in social information use in adults (Molleman, van den Berg, & Weissing, 2014; Toelch, Bruce, Newson, Richerson, & Reader, 2014), such that individuals resemble conformists or mavericks (Efferson, Lalive, Richerson, McElreath, & Lubell, 2008). Evidence for individual preferences in social and asocial learning in childhood is also emerging (e.g., Flynn, Turner, & Giraldeau, accepted). Children are not indiscriminate and blind copiers (see also Over & Carpenter, 2012, 2013), a finding compatible with the dangers of social learning fixation (or 'cultural conformism',

such as population collapse: Whitehead & Richerson, 2009) and the evolution of contingent strategies that enable individuals to switch between social *and* asocial/individual learning (e.g., Boyd & Richerson, 1995; Enquist, Eriksson, & Ghirlanda, 2007; see also Section 7.3).

Could it be that the challenge of innovation (by modification) in childhood is linked with imitation, such that children's true innovation capabilities are largely overshadowed by an imitative learning bias? Or is it that innovation has a protracted development, reliably emerging much later in childhood when it has a more adaptive function to serve? The answer is likely a combination of both these explanations. Innovation is made more difficult for children immediately following the provision of social information, at least partially owing to their inclination to imitate, and particularly in dyadic contexts (involving an adult and child) where normative expectations for learning apply. Yet, as children's cognitive competency increases, as a result of age and experience (in line with general developmental trends of cognitive improvements throughout childhood), their innovation increases (see also Beck et al., 2011) and imitation decreases (Chapters 3 and 6). It is not that children are incapable of flexibly deploying imitation prior to this time; they evidence selectivity and flexibility in their social learning from an early age (e.g., Koenig & Sabbagh, 2013; Nielsen, 2006). Rather, there appears to be a developmentally-driven leap from the ability to vary the extent and fidelity of one's imitation (dependent upon contextual and social cues) to the ability to produce novel behavioural alternatives.

Interestingly, although this thesis discovered the overall trend was for increasing innovation with age (Chapters 3 and 6), some young innovators were found. This perhaps hints at earlier-emerging innovation capabilities, in those less

constrained by social information, than suggested by the general trends. However, as revealed in Chapter 3, young innovators were considerably fewer in number (five 4- to 5-year-olds and seven 6- to 7-year-olds) than older innovators (fourteen 8- to 9-year-olds). Age differences in (exit) innovators in Chapter 6 (where children received further prompted attempts at the MMB task) were less pronounced, though still in the direction reported here. Also, utilising the operational criteria advanced in Chapter 2, there was some evidence for qualitative differences in the innovation of children at different ages. For example, the discovery of more than one novel exit became increasingly likely with older age, suggesting that older children were more capable of learning, and generalising, from the outcomes of their new behaviour. This supports Legare and Nielsen's (2015) proposal that, with the knowledge and experience of age, innovation transitions from that of a less systematic 'blind' form to a more systematic 'directed' form. The former may be more likely to capture innovations due to accident and chance, and the latter innovations resulting from intentionality. Of course, this is a general supposition; even adults also learn and innovate as a result of serendipitous accident and chance. Whether innovations are accompanied by learning (which may be more likely with advances in cognition) will help determine the cultural consequences of novel behaviour (as proposed in Chapter 2).

7.2 Innovation Can be Theoretically and Practically Delineated

Theoretical work within the fields of cultural evolution and evolutionary anthropology, along with non-human animal research, has been instrumental in establishing different sources (Mesoudi et al., 2013), types (e.g., Ramsey, Bastian, &

van Schaik, 2007) and forms (Lewis & Laland, 2012) of innovation. Not only is there an acknowledgement that these forms have potentially very different cognitive requirements, but their cultural implications are known to vary (Lewis & Laland, 2012). A major question concerns whether such differences and variations may be discerned early in human ontogeny, suggestive of the distinct evolutionary function and development of innovation's various forms.

In the handful of studies that have explicitly examined childhood innovation prior to the work of this thesis, innovation of one particular form had been studied: that of novel invention (independent problem solving). The hook task (e.g., Weir, Chappell, & Kacelnik, 2002; Beck et al., 2011) has been most widely used, requiring participants to innovate a hook (or other functional) tool from a pipe-cleaner in order to retrieve a sticker-containing bucket from the bottom of a narrow and transparent tube. Importantly, this is a task that largely necessitates asocial/individual learning for its solution. The inclusion of 'largely' is an acknowledgement of the fact that children bring prior experience to the task, perhaps acquired socially, that provides some understanding of the properties and uses of pipe-cleaners; it cannot be said, therefore, to be entirely independent of social influence. Nonetheless, the task cannot either be said to heavily or directly implicate social information: children are presented with the task without opportunities for specific task-related prior social learning. Yet, it is often an evaluation of information acquired socially that induces innovation. Judging "that a novel solution to a problem generates superior returns than does an (observed) established behaviour" (Laland, 2004, p.10, parentheses added), and proceeding to modify existing behaviour in such a way as to theoretically improve it, is a process or form of innovation that is quite different to that described above. Moreover, as will be discussed further, it requires somewhat

distinct skills. Given that innovation has a number of forms, of which novel invention is only one, it makes sense to consider and examine the various guises of innovation, especially when seeking to determine, and make generalisations about, children's capabilities in this domain.

In Chapter 2, the argument was advanced that innovation may be advantageously delineated into innovation *by novel invention* (when novel behaviour results from asocial learning) and innovation *by modification* (when social influences are directly implicated). Whilst this thesis empirically examined both forms, by presenting the MMB task in the absence of prior social demonstrations (Chapter 3, control group, and Chapter 5) and following social demonstrations (Chapters 3 and 6), the latter have been of particular importance in providing support for the proposed invention-modification distinction. As theorised, findings suggest that these two forms of innovation do indeed possess distinct developmental trajectories (though the extent to which this is task-specific needs to be examined) and have different primary difficulties (indicative of different cognitive requirements) associated with them. The two developmental trajectories have already been touched upon in Section 7.1. Whereas Beck et al. (2011) discovered children to reliably innovate by independent invention (perform at 'mature levels') on the hook task at around 8-9 years, with 80% of individuals at this age producing a hook or other functional tool, innovation by modification was challenging even for 8- to 9-year-olds in their interactions with the MMB task following social demonstrations (Chapter 3). Specifically, only 14 of 72 children aged 8-9 years (19.4%) successfully discovered an alternative exit for the capsule reward. This was in contrast to 9 of 15 children (60%) of the same age group from the control condition (no social demonstrations) who discovered at least one exit. Though not directly comparable, it

is also worth noting that nearly all of the 8- to 9-year-olds (96%) who participated in the normative study (Chapter 5), without prior social demonstrations of MMB use, innovated in this manner. Omitting demonstrations and including peer-reference and social comparison information in the task instructions bolstered innovative performance (Section 7.4).

In the experimental tasks overviewed, the emergence (or reliable appearance) of innovation by modification appears more delayed than that of invention¹. This raises the question as to whether they have different underlying cognitive mechanisms, or whether novel modification is ostensibly of greater difficulty and thus more reliant upon the knowledge and cognitive abilities that accompany age and experience (e.g., greater inhibition abilities). In order to successfully modify socially-acquired behaviour, one must not only recognise where improvements can be made but override components of observed behaviour *and then* physically produce the novel solution. This thesis provides evidence that doing so is difficult for children even when confronted with an instrumental task and an explicitly-stated goal, conditions which theoretically allow for greater variability and innovation (Legare & Nielsen, 2015; Legare, Wen, Herrmann, & Whitehouse, 2015). Nonetheless, the task was situated within a social context, with pedagogical cues and intentional demonstrations, inducing possible interpretations of conventionality. The developmental trends uncovered in Chapter 3, with imitation decreasing with age and innovation increasing with age, strongly suggest that innovation by modification

¹ A critical caveat to this observation concerns the age/status of the individual from whom the to-be-modified social information is acquired. Tennie et al. (2014) provide recent evidence that children are capable of innovatively modifying inefficient behaviour (altering tool selection) when observing peers, but not adults. This further reinforces the likelihood of innovation being constrained by normative expectations of social learning from adults (compounded by pedagogical demonstrations).

is constrained by immaturity, supporting a competence-based interpretation of its development.

Primary difficulties associated with the two forms of innovation may stem from the information with which children are initially equipped. Whilst the ill-structured nature of tool innovation tasks is posited responsible for children's difficulties in the case of invention (Cutting, Apperly, & Beck, 2011; Cutting, Apperly, Chappell, & Beck, 2014), this cannot fully explain children's difficulties with modification. That is, children do not necessarily lack the transformation information that is required to get from a start-state to an end-state; rather, they must modify the end-state and/or process. Factors linked to the prior provision of social information (including an imitative learning bias, interpretations of conventionality, desire to affiliate, behavioural canalisation, inhibitory control, and functional fixedness) play a considerably larger role in the case of modification than invention. Even with more time to explore the MMB (Chapter 6), rates of innovation were still not seen to be as high as that reported by Beck et al. (2011) for invention. Such observations are in keeping with children's more limited spontaneous exploration following pedagogical demonstrations (e.g., Bonawitz, Shafto, Gweon, Goodman, Spelke, & Schulz, 2011).

In Chapter 4, the individuals identified as innovators (Chapter 3), and their matched imitator pairs, underwent further testing six months later. The hook task was one of several problem-solving tasks administered. Consistent with the theoretical separation of invention and modification, the innovators on the MMB (modification) task were no more likely than their matched imitators to solve the hook (invention) task. If the two tasks are assessing the same form of 'innovation', we might have expected the innovator-imitator groups to be differentiated on both.

Importantly, as set out in Chapter 4, the MMB *does* appear to be measuring what it was designed to assess, increasing confidence in its findings. Specifically, children evidenced some consistency in their behaviour on the MMB, glass-ceiling box, Pan-pipes, and cumulative problem-solving box; suggesting that the MMB is performing similarly to existing tasks in the social learning field, validating its use and the findings presented throughout this thesis.

Could it be that the MMB and hook invention task are simply of differing difficulties, with one more within children's zone of proximal development (Vygotsky, 1978) than the other? Given that the same number of innovator and imitator children solved the hook task (8 of 23 from each group) and failed the hook task (15 of 23 from each group), this is unlikely to be simply a difficulty issue. However, task difficulty is still important to consider and could account for some developmental differences in observed abilities. For example, children's success rates in the floating peanut task (Hanus et al., 2011), assessing invention, resembled those of 'bucket task' success in Beck et al. (2011) but the percentage of children solving the floating peanut task at 8 years was lower by comparison (58% versus 80%). Future innovation research with other problem-solving tasks and puzzle boxes, including children beyond the age of 8-9 years, will more firmly establish reliability in developmental differences as a result of tasks and as a result of the invention-modification differentiation. Yet, there are very likely disparities in the difficulties of invention and modification, and it remains one of the central arguments of this thesis that these difficulties, viably arising from the major source of information with which individuals are initially equipped (asocial or social), are responsible for varying observations of innovation's developmental trajectory (Chapter 3; Beck et al., 2011).

Consideration of different forms of innovation is imperative when seeking to make inferences about children's capabilities. The implications, however, extend beyond that of experimentation. In fact, this is an issue that impacts upon all aspects of innovation research as identified in the introduction to this section, including the design of interventions to promote the innovation process. Such interventions will need to be targeted to the specific challenges that individuals confront, such as whether the ill-structured nature of novel problems or functional fixedness is likely to be the primary obstacle, and whether new or pre-existing knowledge must be applied to a problem (Kummer & Goodall, 1985) and, thus, whether social information is implicated and must be overcome. Chapter 5 is a ready illustration of the need to tailor potential interventions/cognitive support to the form of innovation being assessed. Children's innovation on the MMB task, when social demonstrations were absent, was not facilitated by the provision of 'positive' normative verbal information. Whilst various explanations were offered to account for this finding (including older children's greater normative flexibility, lack of pressure to 'conform' to the stated behavioural norm, and the greater salience of individual achievement goals), it is possible a different result would have been found had normative information accompanied social demonstrations and corroborated the referenced normative behaviour. Together with the findings presented in Chapter 3, this study suggested that normativity has a larger role to play in innovation by modification than innovation by novel invention, when imitation and conformity are typically seen to accompany conventional interpretations of observed behaviour.

The mediating role of imitation in innovation is being increasingly recognised, and there is clearly vast potential to generate complementary insights into both learning mechanisms (and how children negotiate between them) when

examining how they work in tandem (Legare & Nielsen, 2015) – such as in the investigations of innovation by modification contained within this thesis. Imitation, or ‘summative imitation’, is also implicated in innovation by novel combination (Subiaul et al., 2015). Innovating *via* imitating suggests that imitation could potentially *facilitate*, as well as constrain, novel behaviour production, and contribute to cumulative culture (and the operation of the cultural ratchet; Tomasello, Kruger, & Ratner, 1993) in different ways – beyond allowing for high-fidelity information transmission. Further, the cultural implications of trait combination (the “bringing together of two established traits to generate a new trait”; Lewis & Laland, 2012, p.2171) appear more profound than those of novel invention (Lewis & Laland, 2012), and even novel modification/refinement. It may be of particular importance to dedicate future research to those forms of innovation that strongly drive the ratcheting process. A further implication of breaking the barriers between imitation and innovation concerns the need for a re-conceptualisation of innovation: it evidently is not always an asocial or individual learning process (Subiaul et al., 2015; Chapter 2).

7.3 In the Context of Novel Tool-Use Tasks, Children’s Innovation Appears More State- Than Trait-Based (Although Both are Likely of Importance)

In addition to the development and forms of innovation, this thesis addressed a critical question concerning the consistency of individual differences in innovation and potential ‘properties’ or characteristics of innovators. The research contained within Chapter 4 was not only a response to the findings of Chapter 3 (in which a small subset of children distinguished themselves from their peers by innovating),

but, in a novel contribution to the field, a much-needed evaluation of whether innovation appears more of a personality trait in humans, as suggested by non-human animal research, or state-dependent (the result of demographic factors such as age and sex, or context, motivation and necessity).

This objective was achieved in Chapter 4 by examining individual differences in constructs of theoretical and/or empirical relevance to innovation, including social learning, asocial problem solving, cumulative problem solving, and divergent thinking, in children who were earlier differentiated by their innovative and imitative behaviour on the MMB task (Chapter 3). Children evidenced only selective consistent individual differences in the ‘efficiency’ of their behaviour on related puzzle box-type tasks (hinting at domain-specificity of the observed effect), reflective of distinct propensities or preferences for asocial/individual learning. Adults’ innovation on the MMB could not be predicted by their performance on any of the assessed related constructs. Whilst there was some further evidence for consistency in children’s innovativeness between Phase 1 with the MMB task (Chapter 3) and Phase 2 (Chapter 6), with past innovation positively correlated with future innovation (akin to findings in non-humans, e.g., guppies: Laland & Reader, 1999), it is not possible to exclude an effect of learning which would have similarly served to promote continued discoveries of novel alternative exits.

Supporting the state-based interpretation of innovation advanced in Chapter 4, additional thesis findings indicate that innovation in humans is driven by contextual factors: by demonstrating that innovation, as measured on the MMB task, can be induced with inefficacious social information (Chapter 3) and enhanced with time and instructions to explore (Chapter 6). This would surely not be expected if individuals’ innovativeness was, in some way, ‘fixed’. It may be that consistent

propensities or preferences for social or asocial information exist (for which we provide partial support; see also adult samples: Molleman et al., 2014; Toelch et al., 2014), but not at the expense of the capacity to flexibly and adaptively alter behaviour and switch strategies when required. Although “it is not yet known how humans combine social and asocial learning so efficiently to generate cumulative learning” (Ehn & Laland, 2012, p.103), the beginnings of which are evident in childhood (Chapters 3 and 6), adaptive rules that help direct who, when, and what to copy (‘social learning strategies’: Laland, 2004; ‘transmission biases’: Boyd & Richerson, 1985) go some way towards providing an explanation. Moreover, theoretical cultural models, such as that of Enquist et al. (2007), capture a (conditional) critical social learning strategy, in which learners transition to individual learning when socially-acquired behaviour is unsatisfactory. In this way, individual fitness can be enhanced (dependent upon environmental spatial variation; see Rendell, Fogarty, & Laland, 2009) and evolutionary trade-offs between reliance on costly personal information or cheap but possibly less reliable social information avoided (Boyd & Richerson, 1985). By innovating more when faced with unsatisfactory and inefficacious social information (an existing strategy is unproductive and better or more efficient solutions may be sought; Chapter 3), children resemble such ‘critical’ and fluid learners, trading off social information for potentially more reliable personal information when it is adaptive and optimal to do so (Kendal et al., 2009).

These results are ultimately greatly encouraging. By casting into doubt the idea that some individuals are simply naturally more innovative than others, in line with observations of co-variation between innovation and social learning (Reader, 2003; Reader, Hager, & Laland, 2011) and adaptive trade-offs between the two

(Kendal et al., 2009), confidence that *all* individuals can be innovators - whether by natural propensity for asocial information use, with prompts, the provision of appropriate contexts, or sufficient motivation – is heightened.

7.4 A Complex Interplay of Factors Facilitate, and Constrain, Children's Innovation

Research in the social learning field has generated much understanding regarding the contexts and social cues that regulate the extent to which children, at varying ages, imitate observed behaviour. These include: goal understanding (Bekkering, Wohlschläger, & Gattis, 2000; Carpenter, Call, & Tomasello, 2005), cues to behavioural instrumentality or conventionality (Clegg & Legare, in press; Herrmann, Legare, Harris, & Whitehouse, 2013; Legare et al., 2015), behaviour efficacy (Schulz, Hoopell, & Jenkins, 2008; Williamson, Meltzoff, & Markman, 2008), model characteristics such as age, status, and proficiency (see Wood, Kendal, & Flynn, 2013a, and references therein), opportunity for prior personal information acquisition (Wood, Kendal, & Flynn, 2013b), personal (or first-hand observational) experience of task difficulty (Williamson & Meltzoff, 2011; Williamson et al., 2008), and so on. The importance of social context, or perhaps more accurately *interpretations* of social context, and a child's socio-cognitive abilities upon imitative fidelity has been emphasised recently (Legare & Nielsen, 2015; Yu & Kushnir, 2014). Specifically, interactions between social context interpretation and socio-cognitive abilities could be responsible for observed developmental differences in children's imitation. Such a level of understanding will be vital to emulate within the field of innovation research.

Here, the inclusion of a small selection of contexts and social cues known to be implicated in children's imitation is intended to, first, highlight the array of insights that contrast sharply with the comparative few known factors influencing children's innovation, and, second, to make the case that understanding what hinders imitation will aid our understanding of what helps innovation (and vice versa). A number of studies within this thesis have capitalised upon knowledge of when children should viably imitate less, and thus by extension, and with sufficient opportunity to do so, go on to innovate by exploring novel behavioural alternatives.

By discovering increased innovation on the MMB task in the absence of social demonstrations (Chapter 3, control group, and Chapter 5), along with higher rates of innovation in response to low observed behaviour efficacy (poor quality of social information: Chapter 3) and following prompted opportunities for personal information acquisition (time and instructions to explore: Chapter 6), this thesis extends understanding of children's flexible use of imitation and innovation. In this way, it contributes towards objectives to achieve a more 'comprehensive account of cultural learning' (Legare & Nielsen, 2015) that accurately reflects and captures the dual contributions of imitation and innovation. As with imitation, it appears that in the aftermath of social demonstrations children evaluate model characteristics, and the quality of information they possess, before deciding whether or not to innovate. Though Chapter 5 did not find that innovation could be enhanced with 'positive' normative information, relating to the conventionality of peers' task behaviour (referenced children typically find 'lots of ways' versus 'not many ways'), investigations of this kind are still highly valuable in suggesting other factors that are likely to be of importance and interest to innovation. In the work reported here, there is the suggestion that children's innovation could be assisted by inducing mastery or

performance achievement goals, or increasing task-related confidence (see Morgan, Rendell, Ehn, Hoppitt, & Laland, 2011) and, in turn, self-evaluations of competence.

Of the existing studies that have provided insight into the factors that affect children's innovation, they suggest that innovation, by modification, is facilitated by: action sequences that prime an instrumental rather than conventional goal (Legare et al., 2015), occasions when a low, as opposed to high, past-proficiency model matches an original solution of the observer (Wood, Kendal, & Flynn, 2015), observation of inefficient solutions from peers (Tennie et al., 2014), and opportunity to interact with a task before witnessing social demonstrations (Wood et al., 2013b, 2015). The overriding impression is that the performance of intentional pedagogical demonstrations by adults, but not peers, *constrains* innovation in the same manner that it does exploration (Bonawitz et al., 2011). Due to the ill-structured nature of tool innovation problems, innovation by novel invention can be aided by observations of pre-made target tools in combination with experience of manipulating tool materials (5- to 6-year-olds, but not 4- to 5-year-olds; Cutting et al., 2014). However, opportunities to manipulate materials without observation of pre-made tools (Beck et al., 2011), instructions to 'make something' (Cutting et al., 2011), and suggestions to try alternative strategies (Chappell, Cutting, Apperly, & Beck, 2013), are not sufficient to help children overcome their difficulties with invention.

In Chapter 2, an individual-level pathway to innovation was formulated. This pathway was pitched as a starting point for considering how the innovation process is facilitated and constrained, and which constructs play a role at each point. With the insights attained from the research within this thesis, and to illustrate part of the

pathway's purpose (to be expanded and improved upon), some modifications are suggested (see Figure 7.1).

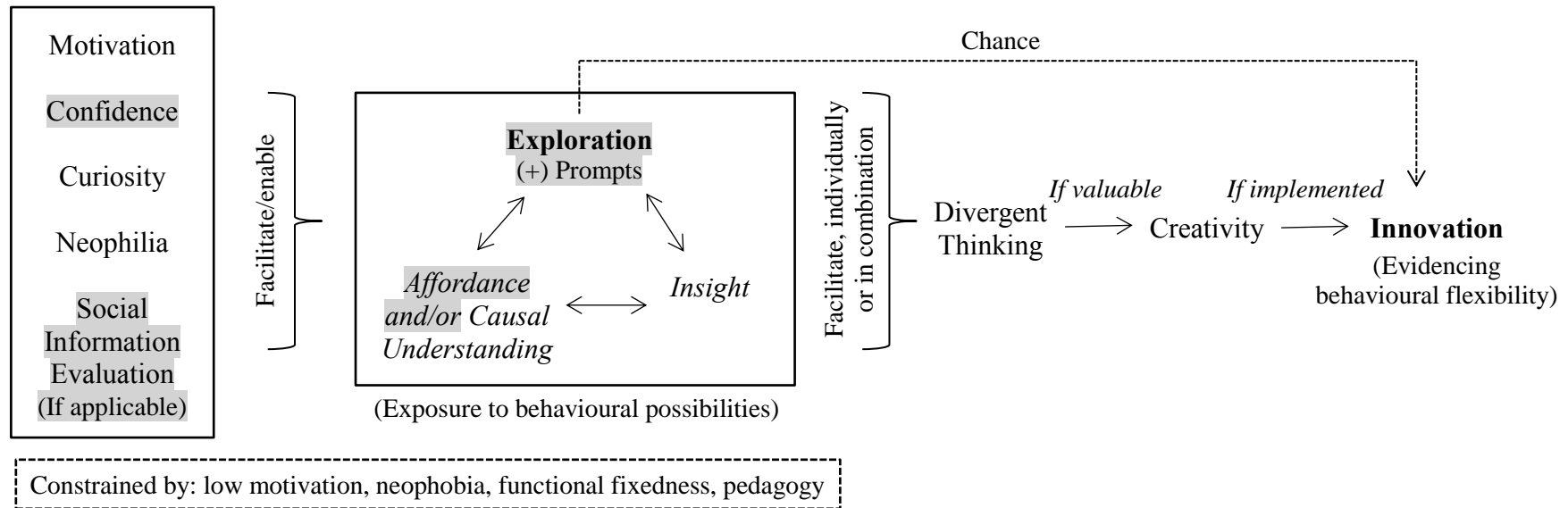


Figure 7.1. An updated hypothetical individual-level pathway to innovation. The following modifications (highlighted in gray and expanded upon in text) have been made: addition of ‘Confidence’ and ‘Social Information Evaluation’ constructs to the left-hand side box; addition of ‘Prompts’ and ‘Affordance and/or Causal Understanding’ constructs to the second box, along with ‘Exploration’ in bold font to emphasise its imperative role in the innovation process.

Starting from the left-hand side of the innovation pathway (Figure 7.1), ‘Confidence’ and ‘Social information evaluation’ now appear as additional contributing constructs. With regard to the former, it was reported in Chapter 5 that children in receipt of peer-performance information that emphasised others’ success were faster at first reward retrievals on the MMB task than those who received information that emphasised others’ lack of success. This is a likely effect of confidence which served to increase the speed with which children initially explored the apparatus. Confidence is seen to decrease reliance on social information in adults (Morgan et al., 2011) and, by extension, viably increase reliance on personal information, serving to promote innovation. Though the role of prior social learning was previously acknowledged to potentially contribute to each construct portrayed, ‘Social information evaluation (if applicable)’ has been added to capture an intrinsic component of the innovation by modification process. This thesis has shown that evaluations of social information, specifically in relation to its efficacy, not only contribute directly to innovation (Chapter 3) but to exploration (possibly via increased task-related confidence that accompanies higher observed behaviour efficacy: Chapter 6).

Exploration now appears in bold font in the Figure to emphasise its crucial role in the innovation process, yet also its distinct qualitative separation from innovation (as originally proposed by Reader & Laland, 2003). With more opportunity to explore, and explicit prompts to do so (hence also the inclusion of a contributing ‘Prompts’ construct to ‘Exploration’), higher instances and rates of not only exit innovations, but tool and access point innovations, were observed in Chapter 6. In support of its qualitative separation, prior observed behaviour efficacy (as determined by experimental condition in Chapter 3) differentially impacted upon

exploration, but not innovation - with one exception. As suggested by this thesis and by the research of Wood et al. (2013b, 2015), wherein children incorporated multiple task solutions (socially- and personally-acquired) into their behavioural repertoires, behavioural canalisation – so often seen in children’s faithful reproduction of observed behaviour (e.g., Hopper et al., 2010) - does not appear to fully characterise children’s difficulties with innovation. Rather, when given sufficient opportunity/attempt trials to explore, they show behavioural flexibility in trying out a variety of different methods (combinations of tools, access points and, though less likely, exits) to solve the MMB task without remaining ‘stuck’ on the particular method that was observed. Adherence to the demonstrated box exit, as seen for the majority of participants in Chapters 3 and 6, more greatly resembled an effect of functional fixedness than canalisation. For alternative exits to be recognised, participants had to reconceptualise the learned design function of the top holes of the box (as exits) which functioned as access points in social demonstrations. When no social demonstrations were provided, as in Chapter 5, the rates of tool, access point and exit innovations were comparable.

Finally, and relatedly, affordance understanding was incorporated into the pathway alongside causal understanding. As explained in Chapter 6, it was not possible to accurately define those parts of children’s exploration that were theoretically directed towards uncovering a causal mechanism for the MMB exit door opening (and thus also subsequent behaviour that stemmed from acquired causal understanding). The absence of discernible causal mechanisms may be true of other instances of situations that require innovation. Yet, with greater experience, and time to interact with, the apparatus, it is highly plausible that children were increasing their understanding of the general properties and affordances of the MMB

and associated tools; for example, learning which tools were best suited to specific access points.

Future research will help to further develop and refine the innovation pathway proposed. However, it will also be essential to look beyond the individual-level process of innovation to its transmission process (i.e., the innovation content, contextual factors and transmission biases that make an innovation more or less likely to be adopted by others), to more accurately mirror cultural transmission and evolution in experimental studies.

7.5 Educational Applications

As humans face a host of environmental, social and economic issues at a societal and global level, taking steps to instil and advance innovatory ability (and the capacity to recognise when and where it may be adaptively implemented) is of great importance. Understanding childhood innovation in the context of tool-use behaviour, amongst others, is a first step. By searching for consistencies in the innovative (and associated social/asocial learning) propensities of individuals at different ages, and consistency in contexts and social cues associated with innovation, it will be possible to identify factors that are regularly and reliably implicated in its appearance. This would, in turn, allow the systematic promotion of innovativeness by way of formulating appropriate educational programs, policies and interventions. Similarly, uncovering obstacles to exploration and innovation production, such as prior social demonstrations, functional fixedness, and lack of opportunity to explore, calls for specific training to overcome them (e.g., McCaffrey, 2012).

Two interventions specifically targeted to innovation by modification have been shown successful in this thesis, and a third proposed. First, innovation can be promoted by highlighting existing behaviour/information that is inefficacious and unsuccessful. Second, giving children time to individually explore, either prior to social demonstrations or *particularly* following social demonstrations, will increase the likelihood of observing novel behaviour. Third, to be verified by future research, increasing children's task motivation by inducing mastery or performance achievement goals (e.g., with individual learning situations or social comparison information) may, in turn, increase their innovation.

The thesis findings importantly corroborate existing and accumulating evidence for the potential detrimental impact of instructions and demonstrations on children's exploratory and innovative learning (e.g., Bonawitz et al., 2011; Wood et al., 2013b, 2015), by producing more conservative learners. As Gopnik (2012, p.1627) writes, "Children's spontaneous exploratory and pretend play is designed to help them learn. And pedagogy can be a mixed blessing. Even preschoolers know when they are being taught, and quickly take on information from teachers. But explicit teaching can also narrow the range of hypotheses that children are willing to consider." Of course, this is not to advocate a sole or primary focus upon individual discovery learning in educational settings; clearly, instruction has a vital role to play in children's learning (e.g., Chen & Klahr, 1999; Kirschner, Sweller, & Clark, 2006; Klahr & Nigam, 2004; Toth, Klahr, & Chen, 2000) and learning itself is a patchwork of experiences in which a multitude of strategies and approaches contribute. The potential to integrate and combine exploratory and guidance strategies within educational interventions (Weisberg, Hirsh-Pasek, & Golinkoff, 2013) and strive for 'pedagogical synergies' that balance structure and creative freedom (Cremin,

Glauert, Craft, Compton, & Stylianidou, 2015) is clear. Continuing communication between educational and developmental researchers will only serve to more accurately reflect the conditions in which children's social learning and innovation (or creativity) occurs. Certainly, whilst there will be occasions that better necessitate explicit teaching and the efficient, rapid transfer of information, there are undoubtedly other learning occasions that call for individual exploration and discovery, and even others that call for both.

Children's exploration and innovation appears to require greater support when normative expectations of learning from others apply. In view of children's early-emerging norm psychology (Chudek & Henrich, 2011) and their early displays of conformity (Haun & Tomasello, 2011), educators may be sensitive to learning situations in which interpretations of social conventionality and social pressure may bias and conceal children's true innovation capabilities. In a similar vein, knowledge of model-based biases (Wood et al., 2012) and their effect upon displays of imitation and innovation (Wood et al., 2015), could be advantageously applied in the classroom.

7.6 Limitations and Future Research

The research presented in this thesis has a number of limitations, from which specific avenues for future research are suggested. The first relates to the MMB task, and its use as the sole instrument for assessing children's innovatory abilities. Whilst the design and implementation of this task was necessitated due to the absence of suitable alternative puzzle boxes that would allow for a range of novel behaviours to be produced, and its use was validated in Chapter 4 (behavioural consistency with

other puzzle boxes), the findings reported in this thesis require replication with other tasks. These tasks should be of a goal-directed *and* non-goal directed nature, in order to better understand how children's innovative (and imitative) behaviour is affected by indications and interpretations of instrumentality and conventionality (e.g., Clegg & Legare, in press) – and how tasks with varying combined degrees of instrumental and conventional elements alter adaptive informational trade-offs (of the kind reported in Chapter 3) at different ages.

A participant age range of 4-9 years was selected in this thesis so as to capture developmental change. However, to be fully comprehensive, and appreciate the interactions between age-related changes in cognitive abilities, interpretations of social context, and factors that facilitate innovation, investigations into the innovatory abilities of older and younger children will need to be carried out. Moreover, examining the ontogeny of different forms of innovation, and the difficulties associated with each form *throughout* childhood, will permit insight into how they contribute to cumulative culture. These examinations have already begun in the case of innovation by novel invention (Cutting et al., 2014). The inclusion of adult participants into the research contained within Chapters 3 and 4 was highly useful as a means of performance comparison with the children and for revealing insightful similarities (such as innovation being ostensibly driven by necessity, as opposed to opportunity; as in non-human animals: Laland & Reader, 1999). Yet, the innovation of adults is, of course, remarkably more sophisticated than that of children. It remains to be seen how, and by what means, such leaps in innovative ability are made over the lifespan.

Advances in knowledge and understanding of constructs related to innovation will be of great value in more accurately determining innovation development and

the pathways that lead to its production. However, advances in the *measurement* of these constructs will also be of help. As reviewed in Chapter 2, divergent thinking and creativity are widely-held precursors of innovation. Failure to find the expected relation between these constructs and innovation in Chapter 4 cannot be taken as an indication of the absence of a relation, but of disparity in the domains (physical versus verbal) in which they were assessed. To verify the contributions of divergent thinking and creativity to *behavioural* innovation (or not), *physical* tasks to assess them are required (e.g., the non-verbal divergent thinking Unusual Box test for young children; Bijvoet-van den Berg & Hoicka, 2014).

Dyadic interactions between an adult and child, though commonly encountered by children in home and school environments and typically utilised in social learning studies, are not representative of the diversity of social contexts and settings to which children are exposed (and in which real-world innovations also appear). Extending research from more solitary settings into ecologically-valid social settings, such as ‘makerspaces’ (Sheridan, Halverson, Litts, Brahms, Jacobs-Priebe, & Owens, 2014), is much needed, and may better reflect the environments in which children arguably display their greatest levels of exploration, creativity and innovation: play (Bateson & Martin, 2013; Nielsen, 2012). Indeed, there is emerging evidence to suggest that children above the age of 3-4 years display greater rates of innovation when presented with the hook invention task in a museum environment, in which they are free to explore and try out materials, than when presented with the same task in a school environment (Sheridan, Konopasky, Kirkwood, & Defeyter, in press). Alternative experimental designs such as open diffusions (e.g., Flynn & Whiten, 2012; Whiten & Flynn, 2010) would also be suited to engendering a more naturalistic view of children’s innovation. Moreover, together with transmission

chains, these designs would be appropriate for answering a greater array of cultural questions regarding the transmission and adoption of innovations once produced (such as in Tennie et al., 2014).

It is not only ecological validity that is largely missing in innovation research, but also cross-cultural investigations. These are crucial in order to establish the extent to which cultural background impacts upon innovation (and other) capacities, and hence to determine their cultural universality. Recently, with this aim, Nielsen, Tomaselli, Mushin, and Whiten (2014) compared the innovative ability of 3- to 5-year-old Western children and children living in Bushman communities in South Africa using the hook invention task. In spite of the vast cultural and environmental differences between these samples of children, both groups evidenced similarly poor tool innovation. This led the authors to conclude that “a capacity for innovation in tool making is seriously lacking in children prior to the formal schooling years even when compared with some non-human species, contrasting markedly with the precocity of children’s social learning dispositions and abilities” (p393). It will be necessary to extend this research with innovation by modification tasks, and observe whether cultural variation in instruction and pedagogy differentially affects the readiness of non-Western children to discard and/or improve unproductive pre-existing social information.

As a final point, it is worth musing on a factor that is undoubtedly a major component of innovation, or any form of behaviour change, yet is very difficult to directly examine and could only be met with speculation in this thesis: motivation. It is possible that those participants who discovered more novel exits in Chapter 3, demonstrated more ‘efficient’ performance in Chapter 4, and went on to discover additional innovations in Chapter 6, were simply more motivated by the

experimental tasks. Operationalising and examining motivation, for example by introducing a motivation rating system into tasks, and its role in innovation is an imperative future line of research.

7.7 Conclusions

The evidence presented in this thesis demonstrates that, though childhood innovation is rare when compared with rates of social learning (and specifically imitation), children are not incapable of innovating. Indeed, the ability to build upon pre-existing knowledge and improve it, which is foundational to cumulative culture, appears present in children given sufficient support. In the current work, this support appeared in the form of inefficacious social information, emphasising the futility of social learning, and sufficient opportunity for the physical production of alternative and successful behaviour. Difficulties with innovation may vary depending on its form, accompanying contextual and social information, and the age of individuals. Thus, when it comes to designing interventions, a one-size-fits-all approach is not appropriate. Confidence in the potential of interventions to enhance and promote the innovation process is gained from findings that innovation appears more state-based than trait-based (in the context of novel tool-use tasks). Innovatory ability should not, therefore, be viewed as fixed or predetermined, but universal. Importantly, to gain a full understanding of innovation, and particularly innovation by modification, it is imperative to consider its social side. This thesis testifies to the necessity and value of the dual study of imitation and innovation, in light of their dual requirement for the operation of the cultural ratchet. The educational implications and

applications of this work are profound, and call for a greater emphasis upon children's individual exploration and discovery.

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Appendices

Appendix Item 1a: Sample consent letter to parents/guardians



Department of Psychology
Durham, DH1 3LE
Telephone: 0191 3343251

25/06/13

Dear Parent/Guardian,

My name is Kayleigh Carr and I am a PhD student in the Department of Psychology at Durham University. I am writing to ask if you would be willing to allow your child to participate in a study that I would like to run at XXX school.

The study considers how children's decisions to copy actions are affected by increasing uncertainty in their outcome. These actions will be performed upon a puzzle box, with the aim to retrieve a reward (a sticker) from inside. I am interested to discover whether children continue to copy actions demonstrated to them regardless of their level of success, or if new methods of reward retrieval may be innovated. It is thought that children's ability to assess the quality of observed information changes with age, and this is why your child is being invited to participate.

Practically, your child's participation will involve them working with me for about 10 minutes in the school. The task is designed to be like a game so that your child enjoys the experience as much as possible. However, should your child wish to, s/he will be free to withdraw from the study at any time. It is requested that the sessions are video-recorded in order to provide a visual aid for analysing the collected data. Certain behaviours may be of interest to me and I may wish to use the footage to illustrate these points to other academics beyond the end of the study, but this would never be used unless I had your consent (see below). The videotapes will be stored confidentially in the Psychology department and then destroyed (except for the brief clips for which I have parental consent to use as illustrations of academic points). All individual results will be strictly confidential and you are free to withdraw your child's results at any time and without giving reason. Finally, I would like to add that this study has the full support of the Ethics Committee at Durham University and I have full CRB clearance as verified by the staff at the school.

Please return the slip below to a member of staff by XXX notifying me of your decision. Should you like any further information, please don't hesitate to contact me using the details above or provide me with your phone number so I can contact you.

Many thanks,

Kayleigh Carr

Child's Name: _____

Date of Birth (DD/MM/YYYY): _____

- I am WILLING/NOT WILLING to allow my child to participate in the study
- I would like further information. Please contact me on _____
- I am WILLING/NOT WILLING for video footage involving my child to be viewed by other academics for research purposes

Signed: _____

Date: _____

Appendix Item 1b: Confirmation of ethical approval for the empirical studies within this thesis

TO: Kayleigh Carr

FROM: Chair, Psychology Department Ethics Committee

DATE: 3 May 2013

REF: 12/26 - Investigating success-variable environments as contexts for childhood exploration and innovation with the use of a novel tool-based task

Thank you for submitting the above application to the Psychology Department Ethics Committee. I am pleased to let you know that your application has been approved. The Committee's approval is conditional upon your meeting requirements indicated below.

You must ensure that the actual conduct of your research conforms to the ethical guidelines of the BPS (July 2004). These are posted in the Ethics Committee folder on Duo. One of the requirements is that participants should be fully informed about the nature of the proposed study. This is particularly important if any aspects of the study are likely to prove distressing to the participant.

You should also note that, according to the BPS, individual feedback to participants regarding their performance on standardised tests should *not* be given by researchers unless they have a professional qualification in psychometrics.

If you are working with children, you are advised to read the Guidelines for Research Involving Children (available on Duo). You will also need to apply for Enhanced Disclosure from the DBS. Details of applying for disclosure are given on Duo.

Conditions

- None

TO: Kayleigh Carr

FROM: Chair, Psychology Department Ethics Committee

DATE: 18 November 2013

REF: 13/12 - Investigating success-variable environments as contexts for childhood innovation (extension to 12/26)

Thank you for submitting the above application to the Psychology Department Ethics Committee. The application has been given reference 13/12: please quote this in any further correspondence with the committee. I am pleased to let you know that your application has been approved. The Committee's approval is conditional upon your meeting requirements indicated below.

You must ensure that the actual conduct of your research conforms to the ethical guidelines of the BPS (July 2004). These are posted in the Ethics Committee folder on Duo. One of the requirements is that participants should be fully informed about the nature of the proposed study. This is particularly important if any aspects of the study are likely to prove distressing to the participant.

You should also note that, according to the BPS, individual feedback to participants regarding their performance on standardised tests should *not* be given by researchers unless they have a professional qualification in psychometrics.

If you are working with children, you are advised to read the Guidelines for Research Involving Children (available on Duo). You will also need to apply for Enhanced Disclosure from the DBS. Details of applying for disclosure are given on Duo.

Conditions

- Completion of a risk assessment and advising the committee of the rating

TO: Kayleigh Carr

FROM: Acting Chair, Psychology Department Ethics Committee

DATE: 20 April 2015

REF: 14/33 – Extension and amendment for 12/26: Investigating success-variable environments as contexts for childhood exploration and innovation with the use of a novel tool-based task

Thank you for submitting the above application to the Psychology Department Ethics Committee. I am pleased to let you know that your application has been approved. The Committee's approval is conditional upon your meeting requirements indicated below.

This is an extension and amendment to a previously approved submission (ref 12/26) to modify the initial verbal framing of the task (from one instruction to three different instructions for different conditions). The approval of this project has also been extended to 31 July 2015 to allow the research to take place during the current school term.

You must ensure that the actual conduct of your research conforms to the ethical guidelines of the BPS (July 2004). These are posted in the Ethics Committee folder on Duo. One of the requirements is that participants should be fully informed about the nature of the proposed study. This is particularly important if any aspects of the study are likely to prove distressing to the participant.

You should also note that, according to the BPS, individual feedback to participants regarding their performance on standardised tests should *not* be given by researchers unless they have a professional qualification in psychometrics.

If you are working with children, you are advised to read the Guidelines for Research Involving Children (available on Duo). You will also need to apply for Enhanced Disclosure from the DBS. Details of applying for disclosure are given on Duo.

Conditions

- The project is undertaken as described in the original ethics submission, other than the modification mentioned in the second paragraph above

Experiment 1: Additional Task Information/Figures

Transparent glass-ceiling box. The glass-ceiling box (GCB) measured social learning ability and the propensity to imitate causally irrelevant actions. Participants received two demonstrations on the GCB with the instruction, ‘Watch what happens, because I’m going to let you have a go in a minute’, followed by five attempts. In line with previous studies (e.g., McGuigan, Whiten, Flynn, & Horner, 2007), demonstrations featured causally irrelevant actions (tapping bolt ends three times, removing both bolts, and tapping a tool into a top hole three times) and causally relevant actions (opening a door and inserting the tool in a hole to retrieve a sticker reward). As the task is a two-action design, the bolts could be either dragged from the left or pushed from the right with a tool. Similarly, the door could be either lifted or slid. Participants only witnessed the drag-bolts then slide-door method as this has been shown to be the most salient method in prior control conditions (Flynn, 2008; McGuigan, 2012). Between attempts, the box was re-baited behind a fabric sheet thus concealing the process from participants. Prompts such as, ‘Now it’s your turn’ or ‘Have another go’ were provided. The transparent version of the GCB was used to make evident the irrelevancy of the first set of actions. Whilst this alteration has not previously been seen to affect rates of imitation in 3- to 4-year-old children (Horner & Whiten, 2005), it may enable older children to assess efficiency more effectively.

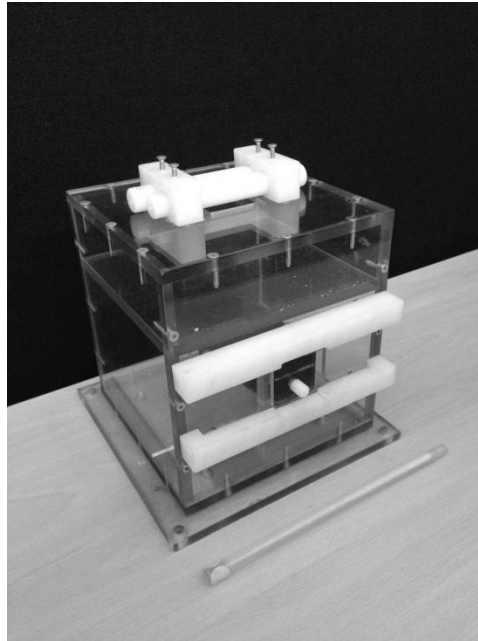


Figure 1. Transparent glass-ceiling box

Pan-pipes. The pan-pipes (PP) is a tool-use task in which the goal is to retrieve a capsule, containing a sticker, by moving an obstruction (a cube-shaped block) behind which the capsule rests in the upper of the two pipes. No demonstrations were provided, thereby allowing an assessment of asocial problem solving. The reward could be retrieved using one of three methods: ‘lift’ (the stick tool is manoeuvred to lift the T-bar on top of the block and allow the capsule to roll under the block and forward to drop into the lower pipe and exit), ‘poke’ (the stick tool is inserted into the front opening of the upper pipe through a small flap door and used to push the block, and hence the capsule, to the back of the upper pipe where it drops into the lower pipe and falls to the exit), and ‘push-slide’ (the stick tool is carefully placed at the base of the T-bar on top of the block and used to push the block and capsule in the same manner as ‘poke’). Participants were given a maximum of 15 attempts or 5 minutes (whichever occurred first) to retrieve the capsule. A new capsule was inserted into the PP following every successful retrieval.

Upon placing the first capsule into the PP, participants were informed: ‘You can do anything you want. You can touch anything on the table. You cannot break it’ (as in Hopper, Flynn, Wood, & Whiten’s, 2010, no-information control condition) and were handed the stick tool. This was repeated if the child failed to interact with the PP after one minute. Following their discovery of a first method (if applicable), participants were prompted: ‘Can you do it any other way?’

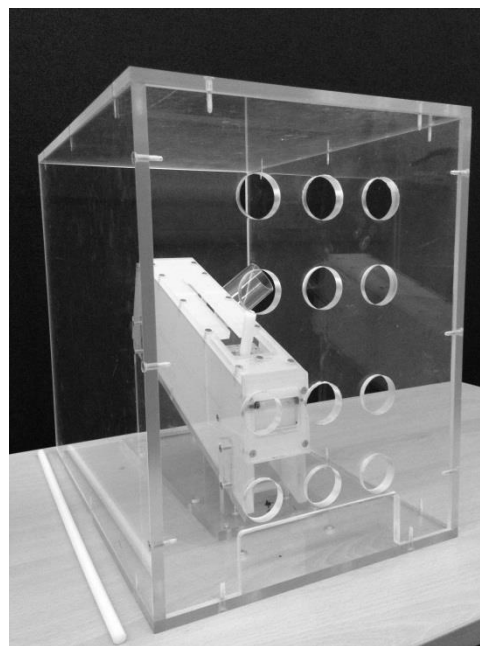


Figure 2. Pan-pipes

Luria hand game. The Luria hand game is a measure of inhibitory control, specifically the inhibition of action. Compared with other inhibitory control tasks, it has low working memory and verbal demands (Simpson, Cooper, Gillmeister, & Riggs, 2013). Participants were first asked if they could show the experimenter how to make a fist with their hand and how they would point their finger. Imitation was then primed with a matching game: ‘Now, when I show you my hand I want you to make the same shape as me. So if I make a fist I want you to make a fist and if I

point my finger I want you to point your finger'. After several of these trials, it could be determined that children had acquired the two actions. Sixteen trials followed in which participants had to produce the opposite action to that of the experimenter. Children were told: 'Now the game gets a bit harder. If I point a finger, then I want you to show me a fist. And if I make a fist, then I want you to point a finger'. To ensure understanding of the rules, there were four practice trials with feedback. The 16 test trials were given in a pseudo-random order (Fist, Point, P, F, P, F, F, P, P, F, P, F, F, P, F, P) without feedback.

Hook task. The hook invention task was comprised of a long, narrow Perspex tube at the bottom of which sat a small bucket containing a sticker, a (29cm) pipecleaner, (29cm) piece of string, and two small (5cm) wooden sticks. The latter three materials were set alongside the tube. The Perspex tube was too narrow to reach into with a hand, thus necessitating the use of the accompanying materials. We replicated the procedure of Beck, Apperly, Chappell, Guthrie, and Cutting (2011) to ascertain children's tool invention abilities; that is, their ability to bend the pipecleaner into a hook and use it to retrieve the bucket by hooking its handle. Unlike Beck et al., we applied a time limit of three minutes as opposed to one minute, allowing a longer time for possible innovation. The following instructions were provided: 'Can you see the sticker in the bucket at the bottom of this tube? If you can get the sticker out, you can keep it.'

Cumulative problem solving box. The cumulative problem solving box (Dean, Kendal, Schapiro, Thierry, & Laland, 2012) measures sequential problem solving, as success on higher (and more difficult) stages of the task are only achieved through success at lower (and easier) stages. The box was baited, in view of the children, with rewards of increasing desirability (two small stickers, two large

stickers, and two erasers). The eraser rewards were introduced so as to provide adequate motivation for the older participants compared to Dean et al.'s study. To retrieve the small stickers (Stage 1), a sliding door had to be pushed in the horizontal plane, exposing a chute through which the reward fell. Stage 2 could be solved by depressing a button on either the lower or higher panel of the box, both of which allowed further movement of the sliding door and exposure of a second chute. The final stage (Stage 3) required the full rotation of a dial, releasing the door to move further along and revealing a third and final chute. The same actions could be performed on both left and right sides of the box, identical in their design. We presented the task to children individually and without demonstrations, stating 'I'm going to put these stickers and rubbers into the box. Let's see how many you can get out'. Children were permitted three minutes of interaction time per stage and were prompted, 'Keep going, there's a way to get to the next one' and 'Do you want to see if you can get any more out?'



Figure 3. Cumulative box

Alternate uses. The alternate uses task (Guilford, 1967) measures children's divergent thinking and creativity. A paper cup and paperclip were selected as two common objects with which children were asked to generate alternate uses: 'Tell me all the different ways you could use this cup/paperclip'. The items were placed in front of participants to provide a visual aid. Verbal responses were given, with the experimenter carefully noting each one. At the first significant pause in children's responses, they were asked: 'Can you think of any more?' If they affirmed they had no further responses, the task ended.

British Picture Vocabulary Scale. The British Picture Vocabulary Scale (BPVS, second edition; Dunn, Dunn, Whetton, & Burley, 1997) was used to assess children's receptive vocabulary ability and to generate a proxy measure of verbal intelligence. In this task, children were instructed to point to one picture, from a choice of four, which corresponded to a word spoken by the experimenter. Testing ceased when a participant made eight or more errors in a set of twelve items.

Sticker disc. The sticker disc (Wood, Kendal & Flynn, 2015) served to assess children's level of neophobia. By situating the sticker disc close to children on the testing table during tasks 6 and 7, any spontaneous touch or verbal reference by the child, prior to its verbal introduction by the experimenter, was recorded. Upon introduction, the instruction was simply, 'I have a new toy, would you like to play with it?' To gain access to one of the six compartments of the transparent Perspex box, within which the stickers were located, a circular panel on top of the box had to be rotated and the circular holes on the panel aligned with those of the compartments. One of two plastic tweezers, loosely attached to the box, could then be used to extract a sticker. The task ended when the first sticker was retrieved, or five minutes had elapsed.



Figure 4. Sticker disc

Experiment 2: Additional Task Information/Figures

Sweep-drawer-lever box. The sweep-drawer-lever box (SDLB: Wood, Kendal, & Flynn, 2013) was selected in place of the pan-pipes to allow for a greater diversity of exploratory behaviours (methods can be combined and order of actions varied). Like the pan-pipes, it is a puzzle box into which a capsule (containing a sticker) is inserted and held in place by defences. Three box mechanisms can be used to release the reward: a drawer, a sweep and a lever. By pulling or pushing one of these mechanisms, the reward falls to the lower level of the box and may be retrieved by lifting or sliding the exit door. The box is transparent, allowing the functionality of the mechanisms to be deduced.

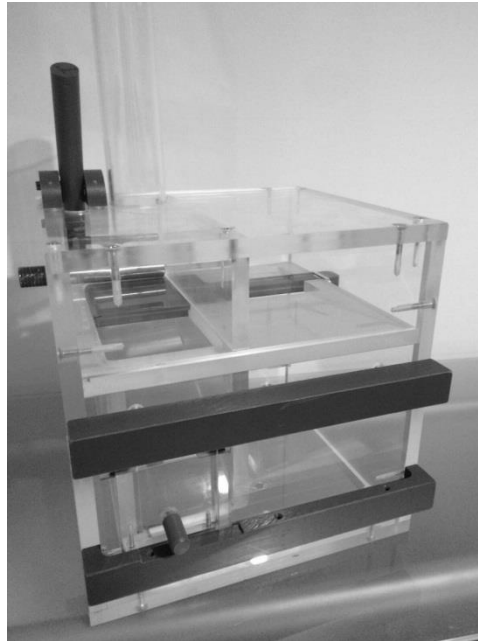


Figure 5. Sweep-drawer-lever box

Inhibitory control: Stop-it. The Luria hand game was replaced with a computer-administered stop-signal task (Logan & Cowan, 1984; Stop-It: Verbruggen, Logan, & Stevens, 2008). The primary task involved discriminating between a square and a circle, presented on screen individually, by pressing associated response keys. However, on random trials, an auditory stop signal sounds requiring participants to inhibit their response. Participants received one practice block before the experimental block commenced.

Invention: Candle problem. The candle problem was developed as a test of problem solving (Duncker, 1945, as cited in German & Defeyter, 2000), requiring participants to attach a candle to a vertical board with only a box of tacks and a book of matches whilst ensuring that the candle does not drip wax onto the surface below. The problem necessitates ‘insight’ inasmuch as participants must look beyond the conventional function of the tack box (holding tacks) and utilise it as a platform or shelf for the candle once emptied. In this way, the problem is also a test of functional

fixedness. Though not directly analogous to the hook task administered to children, it similarly requires the innovative use of materials to reach a solution. Unlike the original candle problem, participants were provided with a box, rather than book, of matches with this intended to be the target (shelf) object. Tacks were provided in a plastic box, and a cork board was placed, and instructed to remain, upright.

Results: GLMMs

The details of GLMM analyses are summarised in the following tables, with the significance of the results explained in the main text.

Section 4.2.2.3

Binomial GLMM (with logit link function)

Can child innovator-imitator group membership be predicted by our seven critical representations of related constructs?

Fixed Effects

	Coefficient	S.E.	t	p	95% CI (lower-upper)
Intercept	1.360	4.216	0.323	.749	-7.209 – 9.928
Glass-ceiling box Irrelevant action score	-0.037	0.031	-1.196	.240	-0.101 – 0.026
Pan-pipes Number of methods	0.500	0.638	0.783	.439	-0.797 – 1.796
Hook task Hook score	-0.902	0.966	-0.934	.357	-2.865 – 1.061
Cumulative box Latency to completion	-0.003	0.003	-1.218	.232	-0.008 – 0.002
Alternate uses Corrected originality	-1.137	1.693	-0.672	.506	-4.579 – 2.304
BPVS Standardised score	0.010	0.033	0.290	.774	-0.058 – 0.078
Sticker disc Latency to first touch	0.048	0.185	0.258	.798	-0.328 – 0.423

S.E. = standard error; CI = confidence interval

Section 4.3.2

GLMM (Poisson distribution with Log link)

Can adults' exit innovation performance on the MMB (including innovation repetitions) be predicted by our selected constructs?

Fixed Effects

	Coefficient	S.E.	t	p	95% CI (lower-upper)
Intercept	-0.100	1.736	-0.057	.955	-3.691 – 3.491
Glass-ceiling box Irrelevant action score	-0.014	0.025	-0.562	.580	-0.066 – 0.038
SDL box Number of methods	0.002	0.133	0.013	.989	-0.273 – 0.277
Stop-It task Stop-it latency	0.001	0.005	0.240	.812	-0.010 – 0.012
Candle problem Candle score	0.089	0.539	0.165	.871	-1.026 – 1.204
Cumulative box Latency to completion	0.000	0.004	0.111	.912	-0.009 – 0.010
Alternate uses Corrected originality	1.173	1.435	0.818	.422	-1.795 – 4.141
Condition (from Carr et al., 2015)	1.277	0.553	2.308	.030	0.132 – 2.421

S.E. = standard error; CI = confidence interval

GLMM (Poisson distribution with Log link)

Can adults' exit innovation performance on the MMB (excluding innovation repetitions) be predicted by our selected constructs?

Fixed Effects

	Coefficient	S.E.	t	p	95% CI (lower-upper)
Intercept	-0.381	1.760	-0.216	.831	-4.020 – 3.259
Glass-ceiling box Irrelevant action score	-0.016	0.026	-0.604	.552	-0.070 – 0.038
SDL box Number of methods	-0.027	0.138	-0.197	.845	-0.312 – 0.258
Stop-It task Stop-it latency	0.000	0.005	0.041	.967	-0.011 – 0.011
Candle problem Candle score	-0.534	0.584	-0.915	.370	-1.741 – 0.674
Cumulative box Latency to completion	0.001	0.005	0.128	.899	-0.009 – 0.010
Alternate uses Corrected originality	2.030	1.521	1.334	.195	-1.117 – 5.176
Condition (from Carr et al., 2015)	1.033	0.554	1.864	.075	-0.114 – 2.179

S.E. = standard error; CI = confidence interval

Descriptive Statistics

Table 1

Descriptive statistics of task measures to evidence an absence of floor and ceiling effects

	Mean	SD	Minimum	Maximum	Range
Glass-Ceiling Box					
Irrelevant action score	40.52	16.65	0	55	55
Pan-Pipes					
Methods	1.30	0.81	0	3	3
Latency to first	104.52	101.57	8	300	292
Hook Task					
Hook Score	0.43	0.45	0	1	1
Cumulative Box					
Cumulative score	2.65	0.77	0	3	3
Latency (first)	17.87	31.04	1	180	179
Latency (all)	244.80	196.51	47	540	493
Alternate Uses					
Fluency	7.85	4.65	1	22	21
Flexibility	5.33	2.08	1	9	8
Elaboration	2.00	3.06	0	14	14
Originality	2.59	2.59	0	9	9
Corrected originality	0.30	0.24	0	0.86	0.86
BPVS					
Standardised score	102.59	12.14	79	131	52
Sticker Disc					
Latency to touch	1.52	2.00	0	8	8
Average latency	81.79	51.61	18.67	202.67	184

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(In addition to those cited in the main text)

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